CRUISE REPORT

R/V ENDEAVOR 2017606

SCOTIAN SHELF

AZMP TRANSECTS +

Leg 1: Nov 24th – Dec 5th
Leg 2: Dec 5th – Dec 16th

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CRUISE NARRATIVE

Highlights

Area Designation:	NAFO Regions: 5Y, 5Ze, 4X, 4W, 4Vs, 4Vn, 3Pn, 3Ps Extent: 41° 51'N - 47° 35'N; 056° 08'W - 066° 08'W
Expedition Designation:	EN2017606 or 32EV17606 (ISDM format)
Chief Scientist:	Dave Hebert Ocean Ecosystem Science Division Marine Ecosystem Section Department of Fisheries and Oceans Bedford Institute of Oceanography PO Box 1006 Dartmouth, NS, Canada B2Y 4A2 David.Hebert@dfo-mpo.gc.ca
Ship:	R/V Endeavor (call sign - WCE5063) Oceanographic research vessel out of the University of Rhode Island.
Ports of Call:	Nov 24th, 2017 – Depart BIO, Dartmouth, NS Nov 26th, 2017 – Arrive BIO, Dartmouth, NS Nov 27th, 2017 – Depart BIO, Dartmouth, NS Dec 5th, 2017 – Arrive Sydney, NS Dec 5th, 2017 – Depart Sydney, NS Dec 9th, 2017 – Arrive BIO, Dartmouth, NS Dec 11th, 2017 – Depart BIO, Dartmouth, NS Dec 16th, 2017 – Arrive BIO, Dartmouth, NS
Cruise Dates:	Leg 1: Nov 24th – Dec 5th Leg 2: Dec 5th – Dec 16th

Mission Summary

Overview

The planned departure of the R/V Endeavor from BIO was planned to be at 1000 LT on November 24th. An issue with steerage delayed departure until 1045 LT. The start of the recovery of the Nova Scotia Current Mooring (M1996) started at 1500 LT and the new mooring (M2024) was deployed at 16:30 LT. Then, we headed to HL_01 to start the Halifax Line throughout the night, completing HL_03.3 at 0630. The AMAR mooring

(M1949) in Emerald Basin was recovered on the 24th on the 25th. We headed back to BIO to wait out an approaching storm, docking at 1830LT. We departed BIO at 1830 LT on the 26th and were running several hours late out to HL_04 due to sea state and weather. The weather was rough throughout the night so we waited until daylight before heading to HL_05. A release test was conducted just prior to the station occupation at HL_06. Stations occupations were then completed in order out to HL_06.3. At 0420 LT on the 28th, the conditions became too poor to continue in the southeast heading so it was decided to change headings to begin mooring work in Dawson Canyon. The weather deteriorated further and a decision was made to hold position near HL_06.7 and heave-to. At 0815LT, it decided to head to HL_06.7 and complete that station in addition to HL_07. Due to time constraints imposed by the planned port call in Sydney and impending weather in the area, the rest of the extended Halifax Line stations were dropped from the schedule.

On November 29th, a series of CTD casts were conducted in Dawson Canyon to await the deployment of the AMAR mooring at first light. The mooring deployment (M2027) was completed at 0930LT and we headed to Logan Canyon. The AMAR mooring at Logan Canyon (M2028) was deployed at 1600 LT and a CTD cast was conducted nearby before heading to the Gully.

While occupying SG_28 on November 30th, conditions deteriorated enough that we could not conduct a vertical net tow. After the CTD cast, we hoved-to until the weather improved. At the same location, a release test was conducted at 1630 LT. We deployed an AMAR mooring (M2026) at 1920 LT at the offshore Gully location and conducted a MCAL survey. The remainder of the Gully station occupations were followed by a recovery and deployment of an AMAR mooring (M1948 and M2025 consecutively) during the afternoon of December 1st.

Following the Gully work, the Louisbourg Line was occupied. After LL_09, the AMAR mooring at Stone Fence (M1950) was recovered at 0930 LT on the 2nd. The Louisbourg Line was completed and the St. Anns Bank Line was started. After completion of the line, the AMAR at the end of the line was deployed (M2029) and another recovered (M1947) on the morning of December 4th. We headed to M1999, a St Anns Bank mooring that could not be recovered on an earlier mission. There was no communication with the release so it is likely that it was released during a previous mission in November. Later in December, the ADCP and SUB were found in Newfoundland. On December 5th, we headed in to Sydney Harbour to disembark some of the science party (Jay Barthelotte, Adam Hartling, Jenni Tolman, Ian Luddington and Jennine Winkel) and the chief engineer. After the change, the Cabot Strait Line was completed on December 6th before heading to STAB_06. At 1600 LT, winds increased and our heading limited our ship speed to 6 kts and later, to 4 kts.

The line across the mouth of Laurentian Channel began in the afternoon of December 7th. The line was completed on the 8th and plans were made to head to BBL_01 to avoid an offshore storm. On December 8th at 1600 LT, the Captain decided the storm on Saturday/Sunday was too large to stay out given our close location to Halifax. We returned to BIO at 1400LT on the 9th. The ship departed BIO at 2130 LT on December 10th.

The Browns Bank Line began at around noon on December 11th. The section across the Northeast Channel was occupied, but BBL_07 was dropped due to impending weather. It was decided to head to the western end of the Yarmouth Line. On the way to YL_10, a CTD cast was undertaken at PL_08 on December 13th. The Yarmouth Line was started at 1430 LT on December 14th. At YL_06, communications to the CTD was lost as it started the upward portion of the cast. A decision was made to switch the CTD/net winches due to a shorted termination on Winch #1. Due to weather and timing, YL_03 was the last station occupied before heading back to BIO on December 15th. HL_02 was occupied before heading into Halifax. The RV Endeavor arrived at BIO at 1545 LT on December 16th.

Over the 23 day mission, the R/V Endeavor logged ~2861 nm and AZMP science staff conducted 175 operations at 87 stations (Figure 1). Table 1 breaks down the operations by sampling gear for each leg of the trip. The table also points to figures that display the deployment locations for each gear type. Each of these figures is accompanied by a table of coordinates detailing each deployment of that gear type. Table 2 contains the break down in time allocated to each gear type.

*Note that approvals for work in the Gully and St. Anns Bank MPA are included in Appendix 1 of this report.

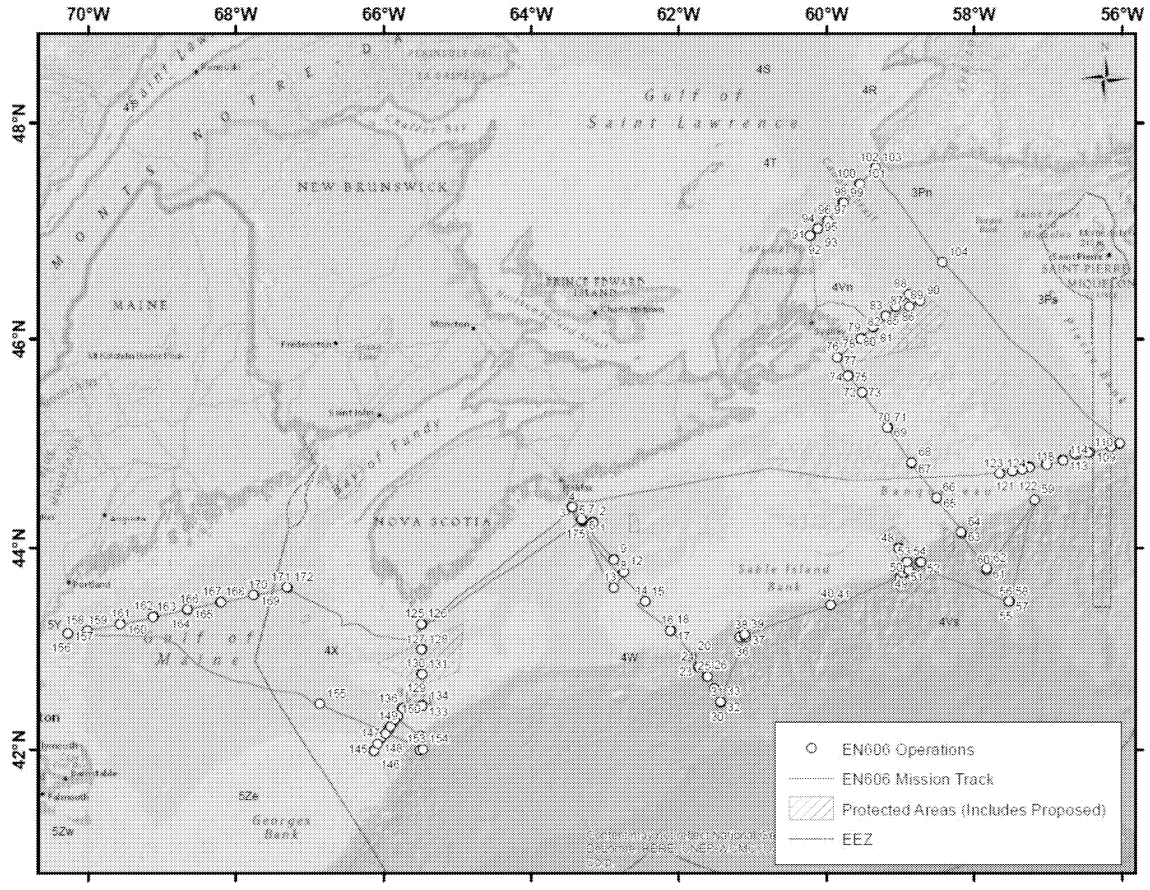


Figure 1. EN2017606 stations. Overlapping event labels may not visible.

Table 1. Station operation summary.

Operation	# of Operations	Figure
CTD	79	2
Vertical Ring Net Tows	76	16
ARGO Float Deployments	6	20
Mooring Recoveries	5	21
Mooring Deployments	6	21

Table 2. Operational time by gear type.

Gear	~Operation Duration (hrs)
CTD	~50
Vertical Net Tows	~24
Mooring Recoveries	~3
Mooring Deployments	~2
Argo Float Deployments	~1

* Surface water parameters were recorded throughout the mission. Refer to the Underway Seawater System Section of this report for more information.

Mission Participants

A complete ship's crew list for this mission can be found in Appendix 2.

Table 3. EN2017606 Science Staff.

	Name	Affiliation	Duty	Leg(s)	Shift
1	Barthelotte, Jay	DFO – OESD	Mooring Ops	1	Day
2	Belzile, Mélany	DFO – OESD	CTD Operator\Elog\Deck Ops	Both	Day
3	Benjamin, Robert	DFO – PCSD	Data Manager	Both	Day
4	Caverhill, Carla	DFO – OESD	Lab Tech\Deck Ops	Both	Day
5	Cogswell, Andrew	DFO – OESD	CTD Operator\Elog\Deck Ops	Both	Night
6	Hartling, Adam	DFO – OESD	Mooring Ops	1	Day
7	Hebert, Dave**	DFO – OESD	Chief Scientist\Deck Ops	Both	Day
8	Luddington, Ian	DAL – Erin Bertrand	Lab Tech	1	Day
9	MacIsaac, Kevin	DFO – OESD	Deck Ops\Biologist	Both	Night
10	Perry, Timothy	DFO – OESD	Lab Tech\Deck Ops	Both	Night
11	Spry, Jeffrey	DFO – OESD	Deck Ops\Lab Tech\Biologist	Both	Day
12	Tolman, Jenni	DAL – Julie LaRoche	Lab Tech	1	Day
13	Winkel, Jeannine	ECCC – CWS	Bird and Mammal Observer	1	Day

**Chief Scientist
DFO: Department of Fisheries and Oceans Canada

Objectives

There were 15 defined objectives for EN2017606. Table 4 describes whether each of these objectives was met along with any relevant supporting commentary.

Primary

1. Obtain observations of the hydrography and distribution of nutrients, phytoplankton and zooplankton at standard sampling stations along "**core**" Atlantic Zone Monitoring Program sections within the Maritimes Region (**Contact Mr. Andrew Cogswell** - http://www.bio.gc.ca/science/monitoring-monitorage/azmp-pmza-eng.php.).

Additional

2. Occupy stations in support of the extended Halifax Line (XHL) (HL_08 and greater) (**Contact Dr. Igor Yashayaev)**
3. Carry out hydrographic, chemical and biological sampling at stations in the Gully in support of Gully MPA monitoring initiatives by Oceans and Coastal Management Division (**Contact Dr. Dave Hebert -** http://inter-w02.dfo-mpo.gc.ca/Maritimes/Oceans/OCMD/Gully/Gully-MPA).
4. Nutrients and hydrography across the Northeast Channel and Gulf of Maine as part of NERACOOS Cooperative Agreement, (**Contact Dr. Dave Hebert** - http://www.neracoos.org/).
5. Deploy 6 ARGO floats in support of the International Argo Float Program (**Contact Dr. Blair Greenan** - http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/argo/index-eng.html).
6. Collect underway and CTD water samples at specified locations and depths to fulfil the regional component of an Aquatic Climate Change Adaptation Services Program (ACCASP) initiative investigating the delineation of ocean acidification and calcium carbonate saturation state of the Atlantic zone (**Contact Dr. Kumiko Azetsu-Scott -** http://www.dfo-mpo.gc.ca/science/oceanography-oceanographie/accasp-psaccma/index-eng.html).
7. Collect water samples for the Bertrand lab at Dalhousie University to evaluate whether and how organic and organometallic micronutrients influence primary productivity and phytoplankton community structure on the Scotian Shelf (**Contact Erin Bertrand** – Erin.Bertrand@dal.ca).
8. Collect water samples from strategic locations and depths to support a microbial community analysis via DNA, RNA and flow cytometry, as well as the isolation of novel diazotrophs (**Contact Dr. Julie Laroche** - http://www.dal.ca/faculty/science/biology/faculty-staff/our-faculty/julie-laroche.html)
9. Bird and mammal observations as part of EC-CWS sea-bird observation program and in fulfilment of Gully MPA occupation requirements (**Contact Carina**

Gjerdrum – carina.gjerdrum@canada.ca).

10. Carry out hydrographic, chemical and biological sampling at stations in the St. Anns Bank MPA as a continued monitoring effort in support of Oceans and Coastal Management Division (**Contact Dr. Dave Hebert -** http://www.dfo-mpo.gc.ca/oceans/mpa-zpm/stanns-sainteanne-eng.html).
11. Attempt to recover a single mooring (M1999) deployed during the fall 2016 AZMP shelf survey (HUD2016027). An unsuccessful attempt to communicate with the acoustic release was made prior to EN2017606 during Dr. Ed Horne's mission aboard the CCGS Perley (Contact **Dr. Dave Hebert**).
12. Conduct hydrographic, chemical and biological sampling across the mouth of the Laurentian Channel (BP and BANQ stations). This transect has been proposed to enhance our understanding of hydrographic phenomenon in these areas in support of current modelling efforts (**Contact Dr. Dave Brickman**).
13. Collect 200 µm ring net zooplankton samples at 8 predefined stations across the Scotian Shelf to supplement the Canada C3 program sample collection (**Contact Dr. Claudio Dibacco -** https://canadac3.ca/en/expedition/the-research/)
14. Recover and deploy the Nova Scotia Current Mooring. This work, funded by AZMP, supports the operation of a mooring that continually monitors the Nova Scotia Current. These data are used to validate shelf circulation models. (**Contact Dr. Dave Hebert**).
15. Recover 4 Autonomous Multichannel Acoustic Recorders (AMAR) from Emerald Basin, the Gully MPA, the Stone Fence Lophelia Conservation Area and the St. Anns Bank MPA. In addition, deploy a total of 5 AMAR moorings; 4 across the eastern Scotian Shelf break at Dawson Canyon, Logan Canyon, and the Gully MPA and 1 deployed within the bounds of the St. Anns Bank MPA. (**Contact Dr. Hilary Moors-Murphy -** http://www.dfo-mpo.gc.ca/science/publications/article/2016/11-15-16-eng.html)

Table 4. EN2017606 objectives status.

Objective	Status	Comments
1	Mostly Complete	With the exception of station BBL_07 all stations were occupied.
2	Cancelled	Due to early delays all XHL stations were dropped.
3	Complete	
4	Complete	
5	Modified Complete	The original plan was to deploy 6 floats at HL_07, 10, 11 and 13; LL_08 and 09. Instead floats were deployed at HL_07(x3), LL_09 (x2) and LL_08.
6	Modified Complete	The sampling depths were modified for the Yarmouth Line. TIC/TA sampling strategy requires adjustment. We only occupied YL_01 to YL_08.
7	Modified Complete	Dal could only participate for the first leg and thus was unable to make collections from the western Scotian Shelf as originally planned.
8	Modified Complete	Dal could only participate for the 1st leg and thus was unable to make collections from the western Scotian Shelf as originally planned.
9	Modified Complete	Bird watcher could only participate for 1st leg. Met requirements of STAB and Gully MPA work.
10	Complete	
11	Failed	We were unable to establish communication with the release and dragging operations were abandoned.
12	Modified Complete	An additional station BP_00 was added to the NL shelf and all other stations were successfully occupied.
13	Partially Complete	Samples were collected from pre-defined stations that were occupied during the mission.

14	Complete
15	Complete

SUMMARY OF ACTIVITIES

CTD Summary

Narrative

As summarized in Table 1, there were a total of 79 CTD casts during the mission (Figure 2 and Table 5). The configuration file used for the mission is provided in Appendix 3.

At the beginning of the mission, DFO staff members were given a tutorial by the Ship's Tech on deploying and recovering the CTD off the starboard side of the vessel. Deployments and recoveries required 1 crane operator and 3 science staff. One science member was responsible for providing hand signals to the crane operator and controlling the swing of the CTD before it reached the rail. The other 2 science staff operated the tag lines on both deployment and recovery. On deployment, tag lines attached to the inboard rail of the ship, would loop the line around the vertical post of the CTD frame and then back to cleat mounted on the deck. On recovery, tag line operators used a long pole to secure a clip to metal extensions radiating from the CTD frame. Once clipped to the frame, they would put the free end of the line around a cleat and pull the line taught, which prevented the CTD from swinging as it was guided over the rail and into position. Once in position, the CTD was secured to the deck with ratchet straps and eyes screwed into the decks bolt pattern.

The ship was able to deploy and recover gear in winds and waves comparable to the CCGS Hudson. Nonetheless, because of the low freeboard and dynamics of the ship, science staff were regularly exposed to wash on the deck both during recovery and deployment and also during water collection.

Water sampling went smoothly but the ship was often required to hold position or steam slowly between stations. This impacted our program efficiency compared to our typical platform. The sampling area around the rosette was somewhat cramped and those sampling the starboard side of the CTD were often exposed to the wind and waves and were precariously close to a very low rail. Initially, water sampling was tricky, because sample bottle racks were brought out one at a time because of the risk of them being washed away or broken deck wash. Half way through the mission, a shelf was created on deck to accommodate racks while samples were being collected. The distance to the lab was minimal and made sampling more efficient. The proximity of lab space to CTD controls also made it simple for staff to stay in communication throughout the mission. Well positioned cameras around the decks of the ship allowed staff to gauge the state of operations.

The CTD performed very well. Only 1 CTD cast (event 165 at YL_06) was aborted when the deck unit through an error. After some quick diagnostic work by the Endeavor Technician, it was determined that the best course of action was to switch the other EM cable and move the net to the cable which required re-termination. This meant a delay of

just less than 2 hours between the recovery of the aborted CTD and its redeployment. For the remainder of the mission the CTD and net were deployed from these new positions.

Overall, science staff were pleased with the experience, competence and helpfulness of the Ship's Tech, Crane Operators, Engineers and Bridge Staff that made these CTD operations a success.

Preliminary section plots of temperature (°C), salinity (p.s.u.) and sigma-t (kg/m^3) can be viewed in Appendix 4.

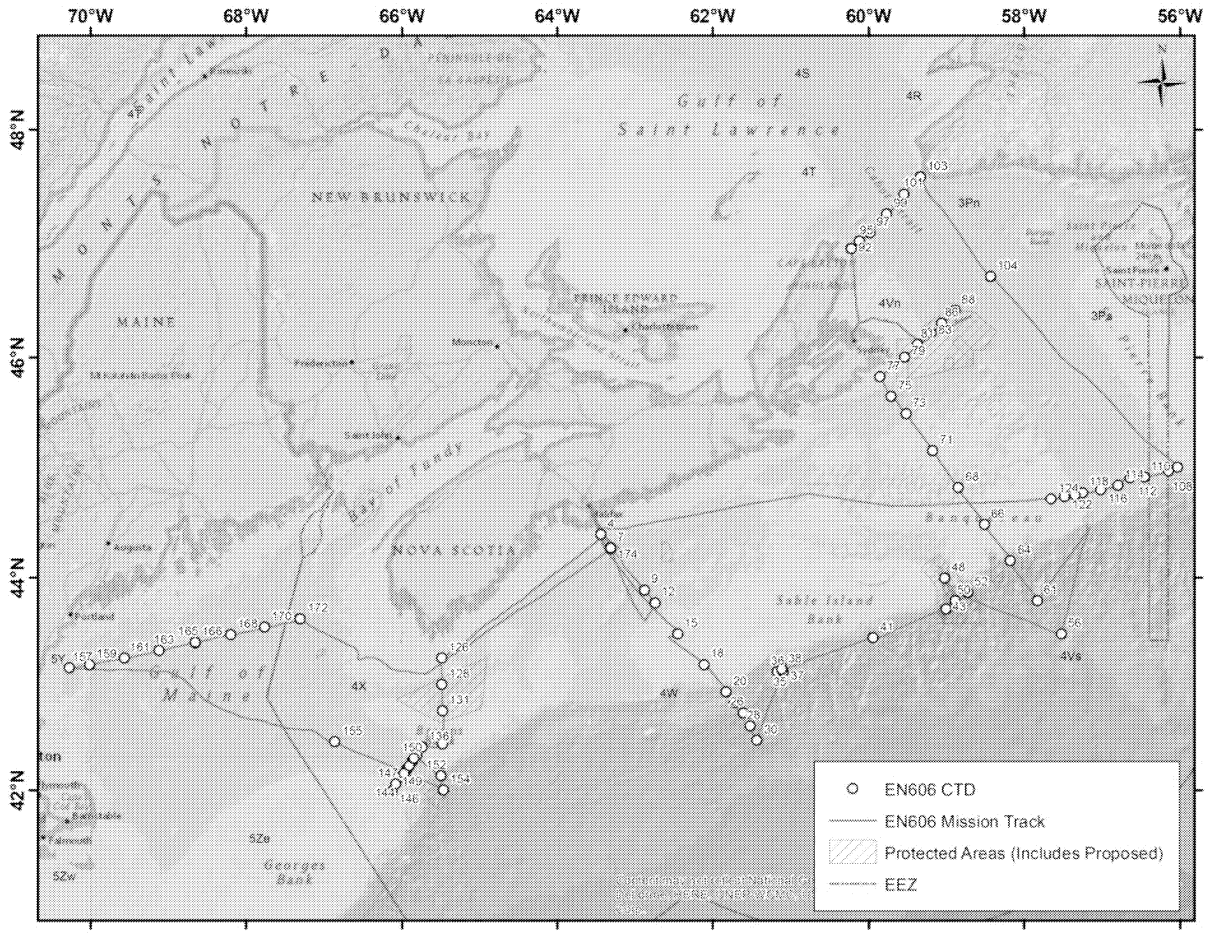


Figure 2. Locations for CTD casts during EN2017606. Each cast is labelled with the consecutive mission event.

Table 5. CTD casts during EN2017606. The coordinates provided are in decimal degrees and reflect the ship's position at the time of deployment as recorded using the ELOG meta-data logger.

#	Event	Station	Date	Slat (DD)	Slon (DD)	Sounding (m)	pH	Water Collected	Aborted
1	4	HL_01	24/11/2017	44.3951	-63.4422	83	X	X	
2	7	HL_02	25/11/2017	44.266	-63.3127	146	X	X	
3	9	HL_03	25/11/2017	43.8832	-62.8829	267	X	X	
4	12	HL_03.3	25/11/2017	43.7645	-62.7484	273	X	X	
5	15	HL_04	27/11/2017	43.4735	-62.4575	82	X	X	
6	18	HL_05	27/11/2017	43.1892	-62.1165	104	X	X	
7	20	HL_05.5	27/11/2017	42.9315	-61.8308	490	X	X	
8	24	HL_06	28/11/2017	42.8322	-61.7306	1136	X	X	
9	26	HL_06.3	28/11/2017	42.7357	-61.6108	1702		X	
10	28	HL_06.7	28/11/2017	42.613	-61.5192	2331		X	
11	30	HL_07	28/11/2017	42.4773	-61.4319	2722		X	
12	34	DC_01	29/11/2017	43.1411	-61.1217	1476			
13	35	DC_02	29/11/2017	43.1702	-61.1221	1489			
14	36	DC_03	29/11/2017	43.1242	-61.1699	1686			
15	37	DC_04	29/11/2017	43.1201	-61.0949	1423			
16	38	DC_01	29/11/2017	43.1436	-61.1213	1422			
17	41	LC_01	29/11/2017	43.4386	-59.9405	1366			
18	43	SG_28	30/11/2017	43.7057	-59.009	1014		X	
19	48	GULD_03	01/12/2017	43.9905	-59.0243	403		X	
20	50	GULD_04	01/12/2017	43.7838	-58.8924	2064		X	
21	52	SG_23	01/12/2017	43.861	-58.7284	1199		X	
22	56	LL_09	02/12/2017	43.4732	-57.5265	3702		X	
23	61	LL_08	02/12/2017	43.7831	-57.8339	2847		X	
24	64	LL_07	03/12/2017	44.1542	-58.1783	755	X	X	
25	66	LL_06	03/12/2017	44.4838	-58.5125	65	X	X	
26	68	LL_05	03/12/2017	44.8234	-58.8496	185	X	X	
27	71	LL_04	03/12/2017	45.1599	-59.1743	109	X	X	
28	73	LL_03	03/12/2017	45.4907	-59.5219	124	X	X	
29	75	LL_02	03/12/2017	45.6501	-59.7094	161	X	X	
30	77	LL_01	03/12/2017	45.823	-59.8547	93	X	X	
31	79	STAB_01	04/12/2017	46.0034	-59.5369	65	X	X	

32	81	STAB_02	04/12/2017	46.1114	-59.3683	65	X	X
33	83	STAB_03	04/12/2017	46.2142	-59.1969	94	X	X
34	86	STAB_04	04/12/2017	46.2997	-59.0658	156	X	X
35	88	STAB_05	04/12/2017	46.4143	-58.8916	386	X	X
36	92	CSL_01	05/12/2017	46.9617	-60.221	82	X	X
37	95	CSL_02	05/12/2017	47.0253	-60.1171	188	X	X
38	97	CSL_03	05/12/2017	47.0991	-59.9867	336	X	X
39	99	CSL_04	06/12/2017	47.2635	-59.7668	472	X	X
40	101	CSL_05	06/12/2017	47.4368	-59.5501	478	X	X
41	103	CSL_06	06/12/2017	47.5827	-59.3336	260	X	X
42	104	STAB_06	06/12/2017	46.7123	-58.4344	475	X	X
43	106	BP_00	07/12/2017	45.0056	-56.0275	103	X	X
44	108	BP_01	07/12/2017	44.9747	-56.1438	233	X	X
45	110	BP_04	07/12/2017	44.92	-56.46	398	X	X
46	112	BP_05	08/12/2017	44.9111	-56.6381	416	X	X
47	114	BANQ_B6	08/12/2017	44.8446	-56.7984	427	X	X
48	116	BANQ_B5	08/12/2017	44.8043	-57.0192	430	X	X
49	118	BANQ_B4	08/12/2017	44.7777	-57.2559	397	X	X
50	120	BANQ_B3	08/12/2017	44.7573	-57.3445	75	X	X
51	122	BANQ_B2	08/12/2017	44.7425	-57.4795	75	X	X
52	124	BANQ_B1	08/12/2017	44.7216	-57.6533	57	X	X
53	126	BBL_01	11/12/2017	43.2467	-65.485	64	X	X
54	128	BBL_02	11/12/2017	43.0008	-65.4813	119	X	X
55	131	BBL_03	11/12/2017	42.7524	-65.4741	101	X	X
56	134	BBL_04	12/12/2017	42.4369	-65.4719	100	X	X
57	136	PS_01	12/12/2017	42.4117	-65.742	100	X	X
58	138	PS_02	12/12/2017	42.3309	-65.8082	206	X	X
59	140	PS_04	12/12/2017	42.2747	-65.8648	227	X	X
60	142	PS_06	12/12/2017	42.2034	-65.9323	227	X	X
61	144	PS_08	12/12/2017	42.122	-66.0237	208	X	X
62	146	PS_10	12/12/2017	41.9869	-66.1267	96	X	X
63	147	PS_09	12/12/2017	42.0615	-66.0793	95	X	X
64	148	PS_07	12/12/2017	42.1633	-65.9656	224	X	X
65	149	PS_05	12/12/2017	42.2328	-65.904	237	X	X
66	150	PS_03	12/12/2017	42.3007	-65.8421	215	X	X
67	152	BBL_05	12/12/2017	42.1387	-65.4969	177	X	X
68	154	BBL_06	13/12/2017	42	-65.4713	1045	X	X

69	155	PL_08	13/12/2017	42.4613	-66.8581	327	X	X	
70	157	YL_10	14/12/2017	43.1548	-70.2741	129	X	X	
71	159	YL_09	14/12/2017	43.1834	-70.0134	89	X	X	
72	161	YL_08	14/12/2017	43.2523	-69.5615	149	X	X	
73	163	YL_07	15/12/2017	43.3182	-69.1170	144	X	X	
74	**165**	**YL_06**	**15/12/2017**	**43.3931**	**-68.6571**	**148**	**X**	**X**	**X**
75	166	YL_06	15/12/2017	43.3989	-68.6562	147	X	X	
76	168	YL_05	15/12/2017	43.4664	-68.2010	190	X	X	
77	170	YL_04	15/12/2017	43.5364	-67.7621	243	X	X	
78	172	YL_03	15/12/2017	43.6131	-67.3036	200	X	X	
79	174	HL_02	16/12/2017	44.2700	-63.3169	150	X	X	

Oxygen

The oxygen data collected by the CTD sensors and Winkler titration method will be used to create new calibration coefficients before the final run of the CTD processing. It will be necessary to extract these corrected oxygen values when they are produced so they can be accurately reflected in our data archives.

The adjusted Soc values are calculated by a 2 step process. First, a "threshold field" is produced that subtracts the mean difference between the sensor and the average Winkler value for all samples, from the individual sample difference between the sensor and Winkler:

(SBE O2 – Winkler O2) - mean(SBE O2 – Winkler O2)

The next step calculates a new slope term by using the following equation:

NewSoc = mean(previousSoc*([Winkler O2]/[SBE O2]))

Before the Soc can be calculated however, comparisons between the primary (#1230, calibrated August 2, 2017) and secondary (#0345, calibrated August 2, 2017) sensors were completed to remove outliers (Figure 3). The 1.5 * inter quartile range (IQR) was used to determine "outlier" data that could bias the results. The first 15 events (444601-444660) showed an average sensor difference greater than the rest of the mission (Figure 3A). The difference during the mission also seemed to be changing slightly. There were some other minor removals, but another sequence of bad data was noticed during CSL_04 (Figure 3B). For oxygen sensors to be this close throughout the mission was actually quite good despite the removal of these outliers before proceeding to the next step.

Comparisons were also made between Winkler replicates (Figure 4). There were a total of 7 Winkler replicates removed from further Soc analysis (events 43, 81, 95, 122, 124, 163 and 174 which correspond to sample ID numbers 444795, 444999, 445062, 445241, 445243, 445492, and 445547). The average difference between the Winkler replicates before outlier removal was 0.002 ml/l. The "threshold field" was then calculated and remaining outliers were removed (Figures 5 and 6). Values beyond the IQR of the difference between the sensor and the Winkler minus the mean difference between the sensor and the Winkler, were removed before calculation of the revised Soc values. For the primary sensor, 17 outliers were removed before calculation of the revised Soc (Events 24, 26, 28, 30 , 43, 48, 52, 56, 61, 71, 116, 118, 149, and 172 which correspond to sample ID's numbers 444701, 444726, 444744, 444752, 444771, 444783, 444786, 444797, 444798, 444833, 444847, 444871, 444929, 445213, 445225, 445397, and 445529). Only one more threshold outlier for the secondary sensor was removed (Event 18, 444677) prior to calculating the new secondary sensor Soc value (Figure 6)

Table 6 shows the previous and revised Soc values and ratio for both the primary and secondary oxygen sensors (#1230 and #0345).

The sensor values were then multiplied by their new corresponding Soc ratios to produce corrected primary and secondary sensor values. This correction brought both sensors closer to at 1:1 relationship with their respective Winkler replicate values (Figure 7). With the corrections applied the mean difference between the average difference between the primary and secondary sensor went from -0.0180 ml/l before correction to -0.0016 ml/l after correction (Figure 8).

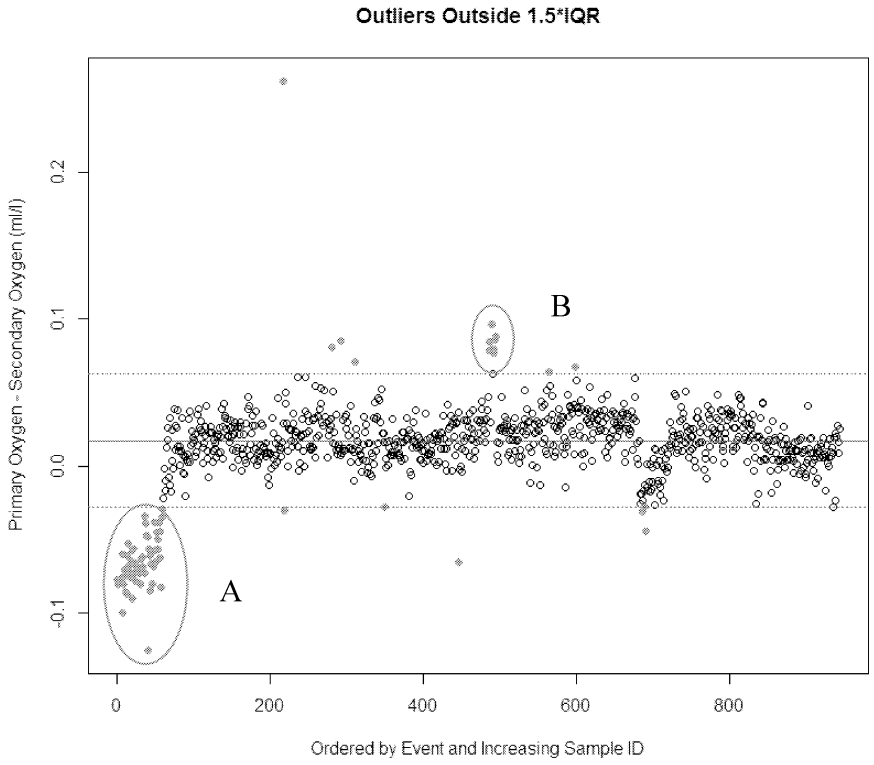


Figure 3. The difference between primary oxygen sensor #1230 and secondary oxygen sensor #0345. Outliers in red were removed prior to proceeding with Soc calculation: **A**) outliers from Events 1-15 (444601-444660), and **B**) Event 99 (CSL_04: 445093 - 445102). The mean difference between sensors before outlier removal (solid blue line) is 0.0168 ml/l. The upper and lower dotted blue lines are 0.0625 and -0.0277 ml/l respectively.

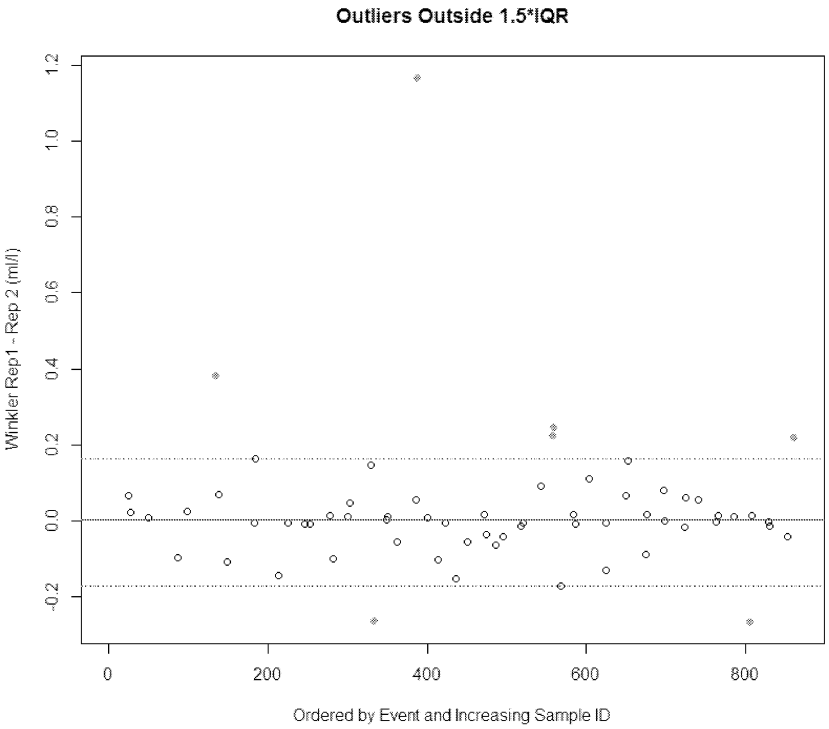


Figure 4. The mean difference (solid blue line) between 1st and 2nd Winkler replicates (-0.002 ml/l). The lower and upper dotted blue lines are -0.17 and 0.16 ml/l respectively. Note the 7 outliers in red that were removed prior to proceeding with Soc calculation (sample ID numbers 444795, 444999, 444062, 445241, 445243, 445492, and 445547).

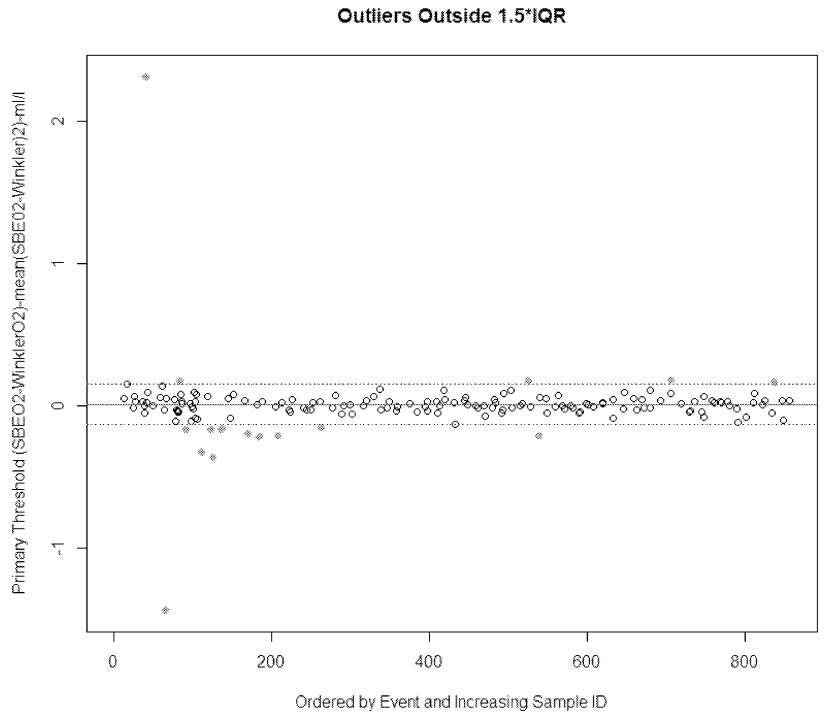


Figure 5. Outlier "threshold" values for the primary sensor were removed. The solid blue line is the mean value of the primary sensor threshold (~0.001 ml/l) and the lower

and upper dotted blue lines are -0.13 and 0.15 ml/l respectively. These outlier data points were removed and the remaining data were used to calculate the primary Soc values.

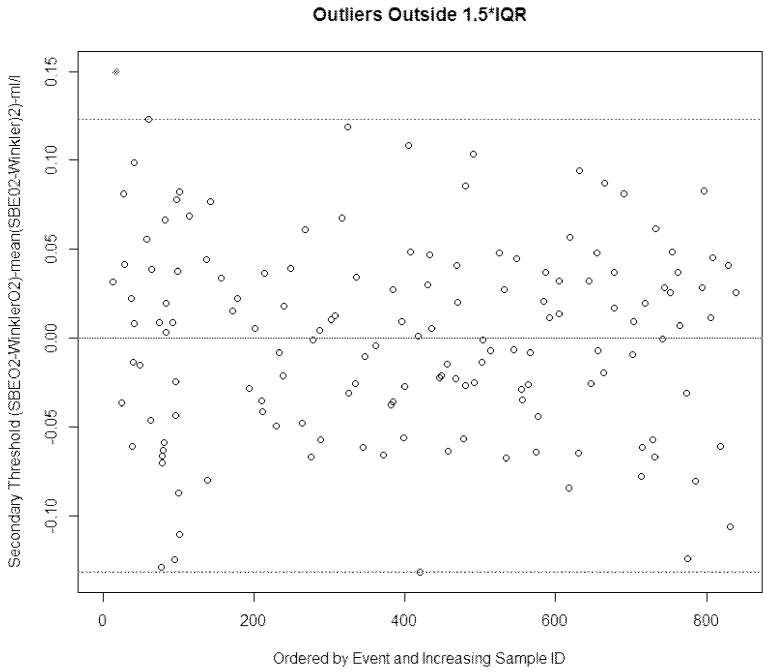
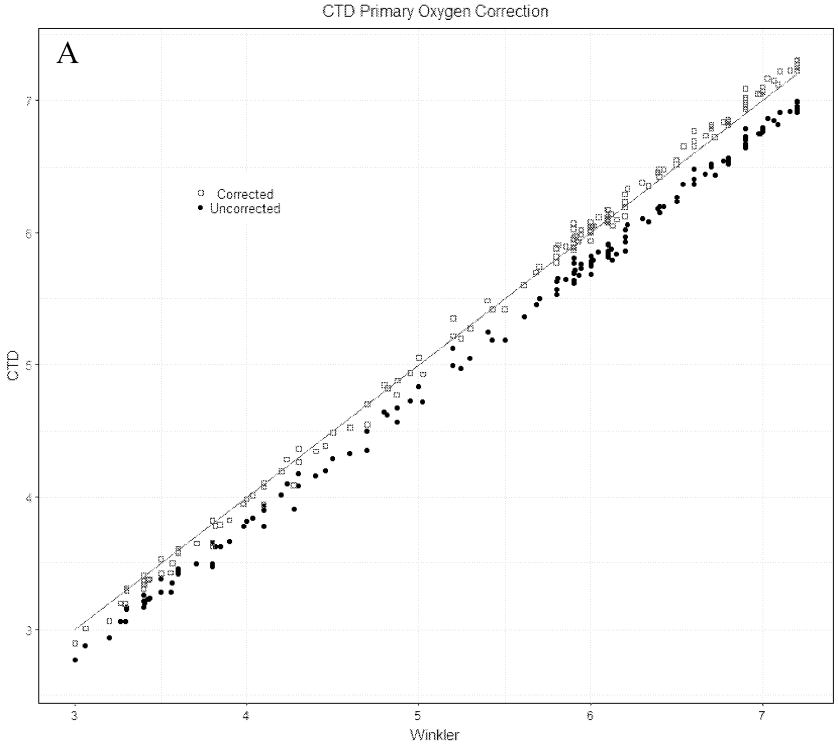


Figure 6. There was just a single "threshold" field value removed for the secondary sensor after the "bad" primary sensor threshold data had been removed.



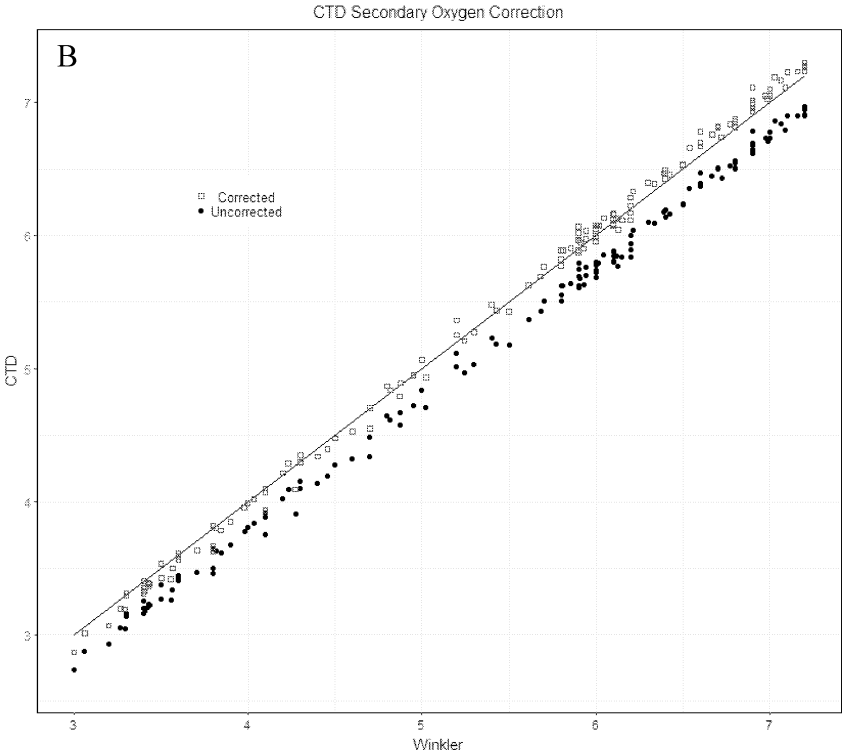


Figure 7. The comparison between the corrected (blue) and uncorrected (black) A) primary (#1230) and B) secondary (#0345) sensors to the mean Winkler value.

Table 6. Old and new Soc values for the primary and secondary SBE Oxygen sensors.

	Old Soc	**New Soc**	**Ratio (New:Old)**
Primary Sensor #1230	5.0347e-1	5.2597e-1	1.044693
Secondary Sensor #0345	3.8281e-1	4.0107e-1	1.047702

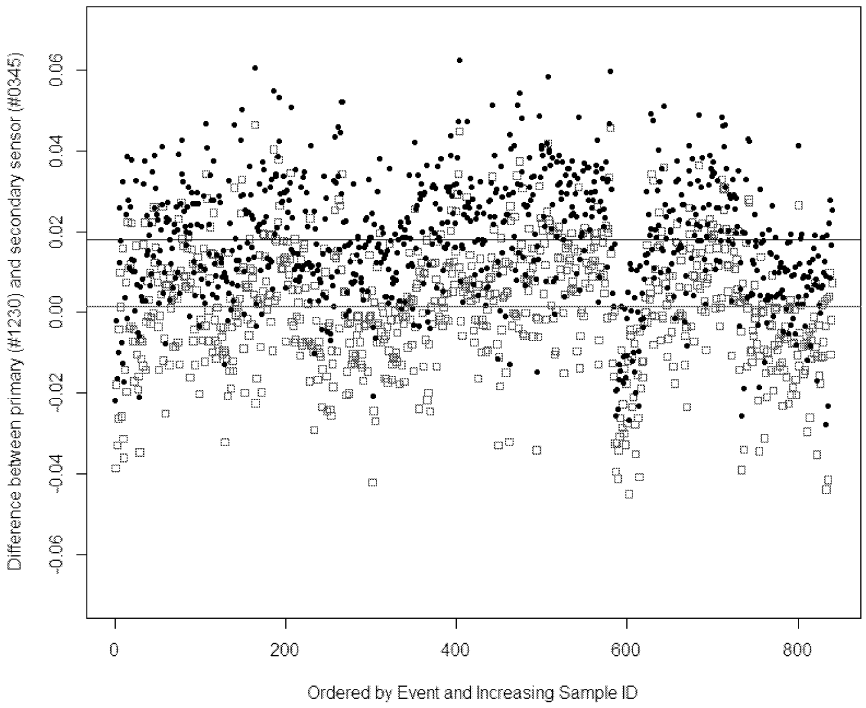


Figure 8. Black dots – non-outlier differences between primary (#1230) and secondary (#0133) sensor values before correction (black line is the mean = 0.0180 ml/l). Blue squares – Soc corrected difference between the primary and secondary sensor (blue line is the mean = 0.0016 ml/l).

Salinity

(With portions extracted from HUD2014017 Cruise Report)

Conductivity Calibration

The salinometer outputs the conductivity as a ratio with the standard; therefore, some conversions are done to get the conductivity of the bottle. The standard has a given K15 value:

K15 = conductivity of standard seawater at 15°C and 1 atm/conductivity of KCl solution (32.4356g/kg) at 15°C and 1 atm.

Where K15 = 0.99984 for this particular standard and the conductivity of KCl standard = 4.29140 S/m and can be found in the seawater Matlab package (gsw_C3515 function). Knowing K15 and the conductivity of the KCl solution, the conductivity of the standard seawater can be determined. Then, by multiplying by the conductivity ratio from the salinometer, the conductivity of the sample can be determined.

It should be noted that these samples were analyzed with a bath temperature of 24°C rather than the 15°C that the standard conductivity was defined. The salinometer program accounted for this temperature difference so that the output sample conductivity ratios with the standard are at 15°C.

Now we have the conductivity of the sample at 15°C and at the pressure of the bath in the salinometer; however, this needs to be converted to conductivity at the temperature and pressure of the CTD. This can be done using some functions from the same Matlab package (adopted for R using the Dan Kelley's oce package).

First calculate the salinity of the bottle using the conductivity and pressure from the salinometer and a temperature of 15°C.

Salinity_bottle = gsw_SP_from_C(Conductivity_salinometer[mS/cm],T[C],P_bath)

Then re-calculate the conductivity from this salinity value using temperature and pressure from the CTD.

Conductivity_bottle = gsw_C_from_SP(Salinity_bottle,T_CTD,P_CTD) %[mS/cm]

This now gives conductivity values that can be compared to the CTD values. To correct the CTD conductivity a linear regression is done on this equation:

$$Bottle\_conductivity = b1 + b2*CTD\_conductivity$$

to find an intercept, b1, and slope, b2, that will make the CTD conductivity better match the bottle conductivity.

Figure 9 shows the difference between the primary (#3220 calibrated Dec 16, 2016) and secondary (#0864 calibrated Dec 15, 2016) sensors throughout the mission, filtered by

IQR to identify outliers. In Figure 10, the difference between the primary and the salinometer is examined and outliers are identified and removed using the IQR method. The mean difference between the primary sensor and the salinometer is -0.007 P.S.U. before outliers are removed, with an upper IQR threshold of ~0.0098 and a lower threshold of -030306. All data points highlighted in red were removed before proceeding.

Figure 11 compares the difference between the secondary sensor and the salinometer and identifies 3 additional outliers that were removed before coefficients were calculated. The mean difference between the secondary and salinometer was -3.45e-03 and the IQR upper limit is 1.05e-02 and the lower limit is -2.13e-02 (dotted blue lines). .

The slope and intercept coefficients for both the primary and secondary sensors after are shown in Table 7. Figure 12 shows the difference between the 2 sensors both before and after correction. Before correction with new coefficients the average difference between filtered primary and secondary conductivity values was –3.36e-02 mS/cm. After correction, the average difference between sensors improved to 6.16e-05.

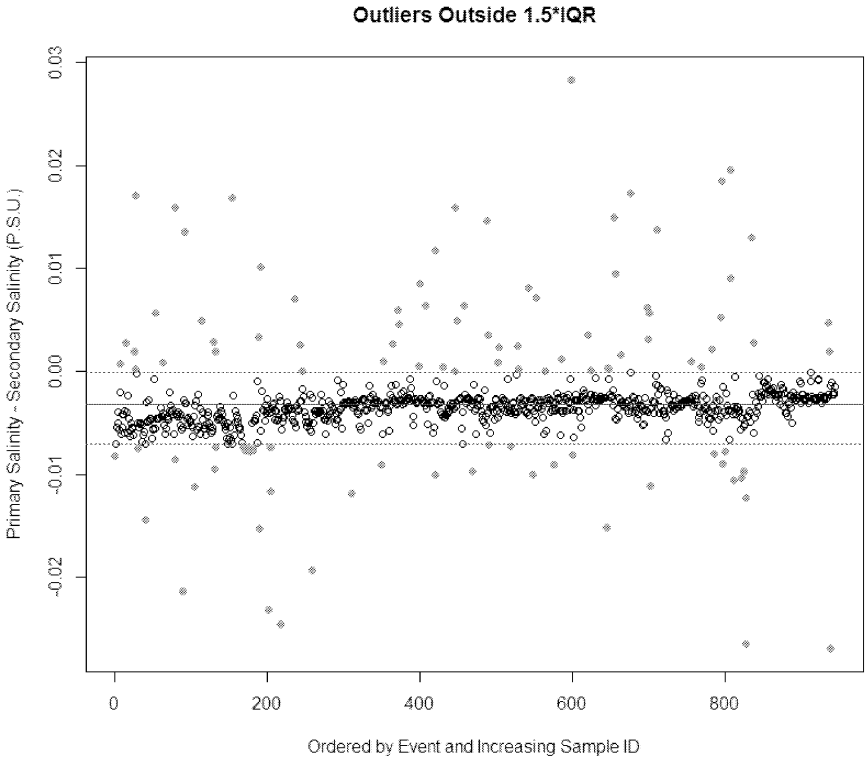


Figure 9. A) The mean sensor difference throughout the mission was was -0.0033 P.S.U (blue line). The lower and upper dotted blue lines are -0.007 and ~0 ml/l respectively. Erroneous data (red dots) were removed before proceeding to the next step.

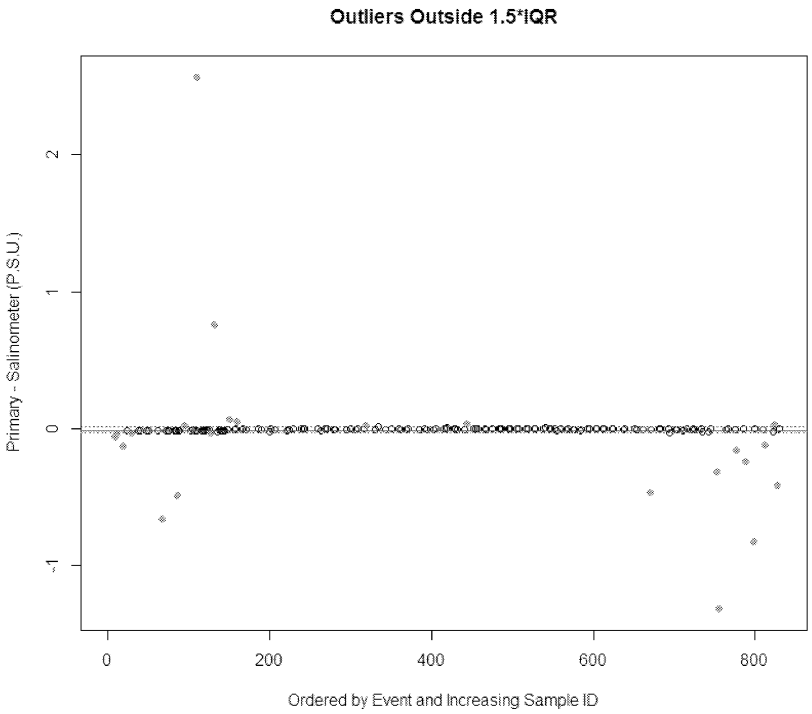


Figure 10. The difference between the primary sensor (#3220) and the salinometer after the removal of erroneous sensor data. Erroneous values (red dots) were removed before proceeding. The mean difference (solid blue line) between the primary and salinometer was 7.00e-03 and the IQR upper limit is 9.80e-03 and the lower limit is -3.06e-02 (dotted blue lines).

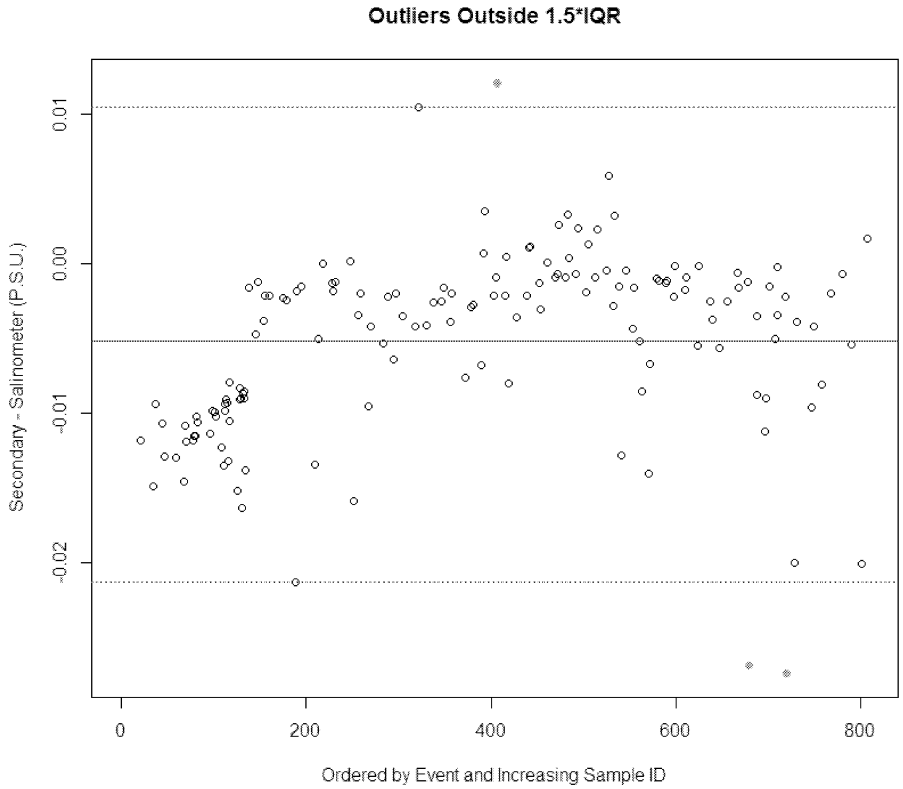


Figure 11. The difference between the secondary sensor (#0864) and the salinometer after removal of erroneous primary sensor and salinometer data. Only three additional erroneous values were removed prior to proceeding The mean difference (solid blue line) between the secondary and salinometer was -3.45e-03 and the IQR upper limit is 1.05e-02 and the lower limit is -2.13e-02 (dotted blue lines).

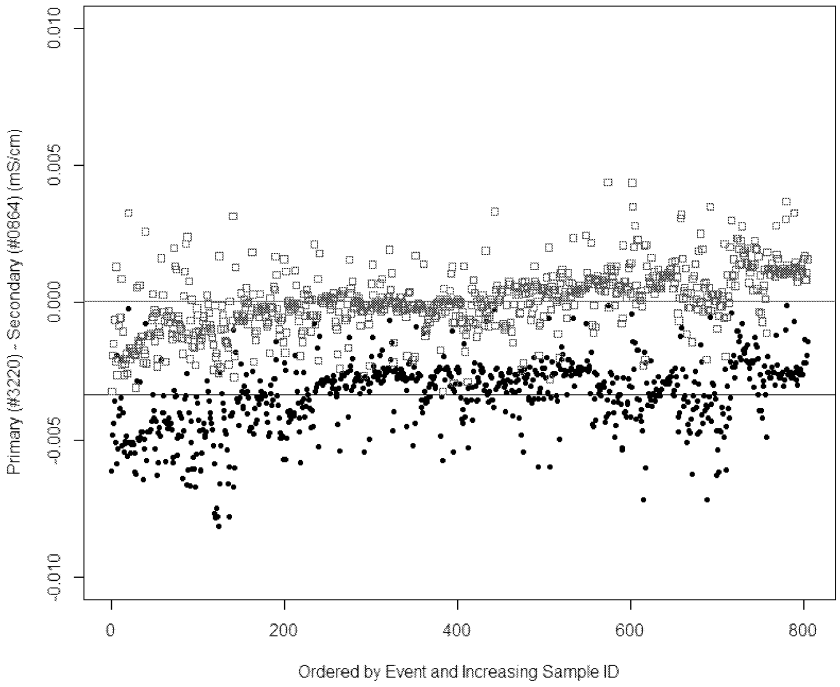


Figure 12. Before correction with new coefficients (black dots), the average difference between primary (#3220) and secondary (#0864) conductivity was –3.36e-03 mS/cm (solid black line). After correction (blue squares), the average difference between sensors was 6.16e-05 (solid blue line).

Table 7. The revised intercept (b1) and slope (b2) terms calculated for both the primary (#3220) and secondary (#0864) conductivity sensors from EN2017606.

Conductivity Sensor	b1	b2
Primary (#3220)	-1.0684e-02	1.000553
Secondary (#0864)	-7.7168e-03	1.000367

Chlorophyll a

Throughout the mission, ChlA was measured in-situ via a Wet Labs Eco-AFL/FL (SN: 492 – calibrated Dec 15, 2016) attached to the CTD rosette (Appendix 3). Duplicate samples were regularly taken for ChlA analysis with a Turner Fluorometer from Niskin bottles fired in the upper 100 m. A comparison of the replicates showed that while the mean difference between replicates was -0.0061 µg/L, there were a total of 98 out of 577 replicates that would be considered outliers (Figure 13). Outliers were selected via the 1.5 * interquartile range (1.5 IQR) method discussed in the previous oxygen and salinity sections of this report. These outliers were removed before making the comparison between the WetLabs sensor values and the mean Turner replicate values (Figure 14). The relationship is confused and appears to be broken into 2 parts. There seems that there could be two separate relationships throughout the mission but the reason for this is

not entirely clear. The relationship is mostly above the 1:1 line from 0 to 0.4, above and below the line at 0.4 to 0.5 and mostly below the line after 0.5. Figure 15 shows the standardized percent difference between the sensor values and the Turner replicate mean throughout the mission. For roughly the first half of the mission (Halifax Line, Gully, Louisbourg Line, St. Anns Bank and Cabot Strait Line), the WetLabs fluorometer registered relative concentrations ~40% greater than the Turner fluorometer. Over the second half of the mission, relative concentrations for both the Turner and WetLabs Fluorometer were roughly equivalent with a mean value of ~ -0.02 %. This suggests that the WetLab fluorometer was more in line with Turner readings for the second half of the mission and because the ship was in warmer nutrient rich waters to the southwest, the ChlA concentrations observed were generally greater. These two factors likely account for the unusual relationship observed in figure 14.

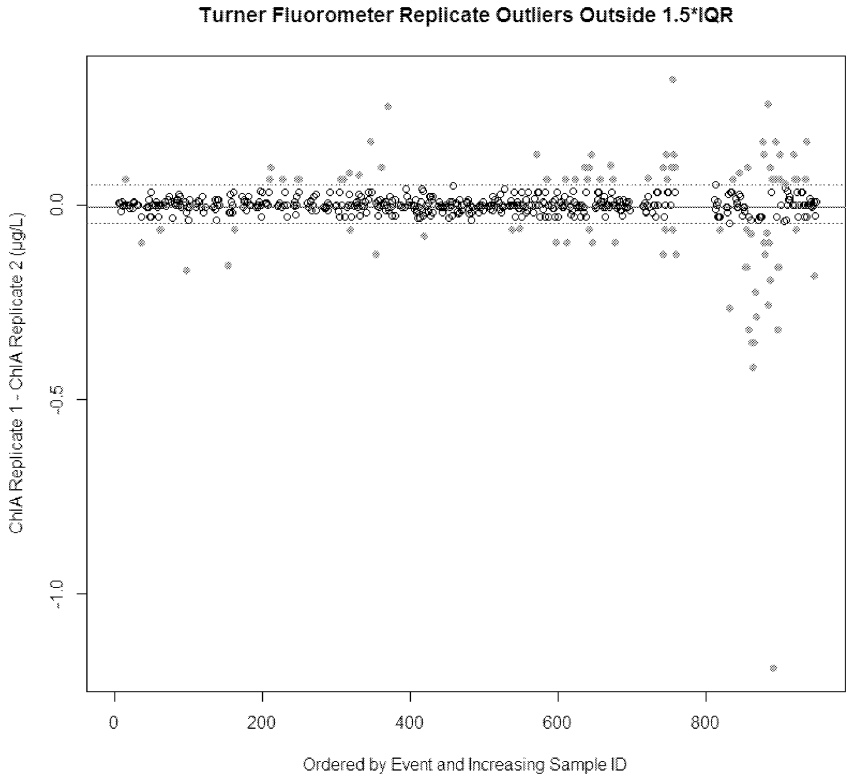


Figure 13. A total of 98/577 Turner fluorometer replicates were considered outliers using the IQR method.

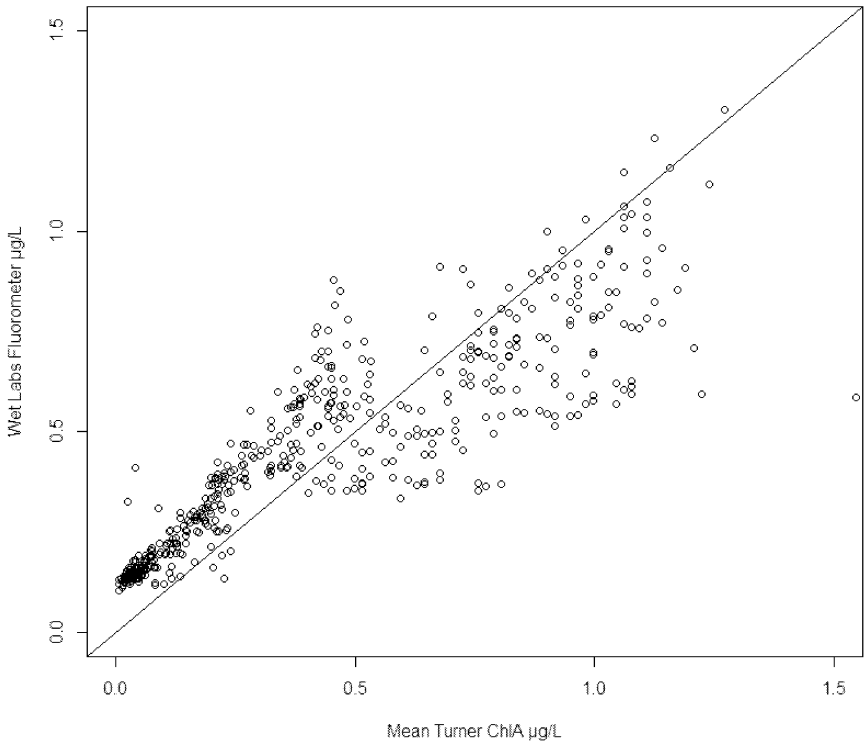


Figure 14. The relationship between the WetLabs Fluorometer and the mean of the corresponding turner replicates.

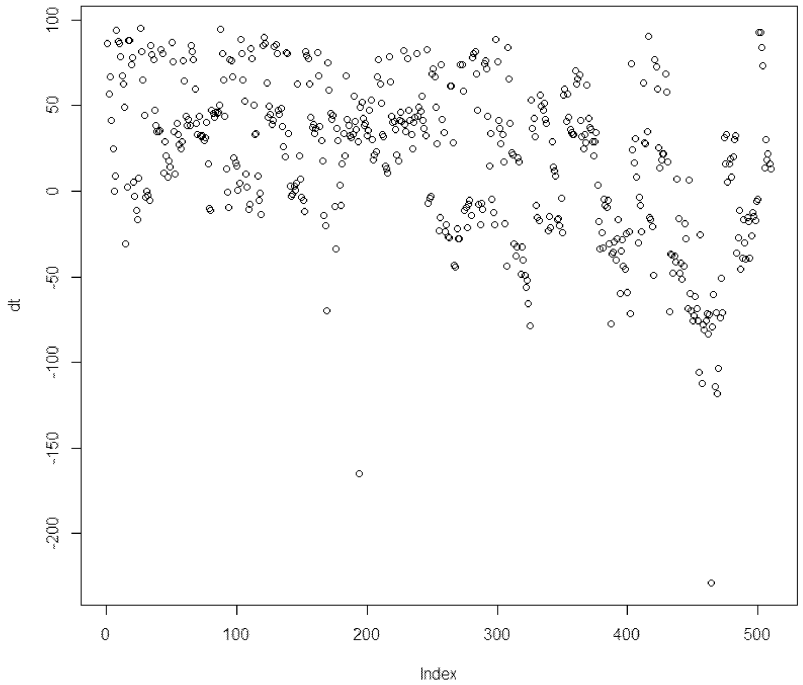


Figure 15. The standardized percent difference between the fluorometer and the mean Turner fluorometer throughout the mission.

Water Samples for Chemical Analyses

Station specific rosette bottle firing depths and water collections for chemical analysis can be found by referring to the CTD deck sheet binder and/or water chemistry sampling document prepared upon the conclusion of the mission and provided to ODIS. Table 5 highlights CTD casts where water collections were made.

pH Sensor

The pH sensor (#1307, calibrated February 3, 2017) was deployed on the rosette only when the maximum depth was less than or equal to ~1200 m. The CTD casts for which it was deployed are noted in Table 5. The sensor was included to support an ACCASP initiative investigating the delineation of ocean acidification and calcium carbonate saturation state of the Atlantic zone.

Biological Program

Narrative

The "core" biological program conducted as part of cruise EN2017606, with some modifications, was a continuation of studies began in pre-AZMP years to describe the large-scale (spatial and temporal) variability in plankton biomass, productivity and biogenic carbon inventories on the Scotian Shelf.

The program currently consists of essentially 2 elements:

1. mesozooplankton community structure, population growth and biomass, and
2. dissolved organic carbon measurements

Table 5 provides a review of the stations where water samples were taken from rosette bottles for element 2 above. The mesoplankton sampling program is described below in more detail. This is followed by descriptions of "non-core" or ancillary biological sampling that includes text describing water sampling efforts in support of projects investigating: organic and organometallic micronutrients and their influence on primary productivity and phytoplankton community structure on the Scotian Shelf (Erin Bertrand – Dalhousie University), and water samples from strategic locations and depths to support a microbial community analysis via DNA, RNA and flow cytometry. The Biological Program section is concluded with a summary of pelagic seabird and marine mammal observations during EN606, provided by Carina Gjerdrum of the Canadian Wildlife Service.

The ultimate aim of "core" studies is twofold:

1. to provide a description of the inventories of biogenic carbon, their turnover rates and variability in space and time as part of Ocean Ecosystem Science Division's (OESD)

continuing climate studies, and
2. to provide a description of plankton life-cycles and productivity on the Scotian Shelf and its influence or contribution to ecosystems in support of OESD's ecosystem-related research.

Mesozooplankton Sampling

Remarks/Comments

In order to estimate the mesozooplankton community abundance and biomass, a conical ring net of 202 µm mesh size with an aperture of 75 cm in diameter (filtering ratio 1:5) equipped with a KC Denmark flow-meter was towed vertically from the bottom to the surface at most stations (or from a maximum depth of 1000 m – AZMP standard). In total, there were 76 vertical ring net tows during the mission (Table 8, Figure 16). Of these, 1 was a 76 µm mesh (30 cm diameter and 1:5 filtering ratio) at HL_02 (event 6). The 76 µm net tow at HL_02 serves the same purpose of quantifying the community but targets a smaller fraction of the mesozooplankton community (i.e. smaller developmental stages, eggs and nauplii). Regardless of the mesh size, contents of the cod end were preserved in 4% buffered formaldehyde. 35 of the 202 µm mesh tows were conducted at stations along core AZMP sections (HL, BBL, CSL and LL) (Table 8). The remaining 40 200 µm casts were conducted at ancillary stations throughout the mission (Table 8, Figure 16).

Six out of 76 casts were aborted for various reasons throughout the mission (HL_03.3, HL_06, HL_06.7, SG_28, STAB_05 and event 173 at HL_02). Of these, HL_06, HL_3.3 and HL_02 were successfully reattempted. It should also be noted that BBL_07 was not occupied because of forecasted inclement weather.

There were 6 - C3 genetics samples taken throughout the mission (of the 8 proposed locations) in support of Objective 13 ("Collect 200 µm ring net zooplankton samples at predefined stations across the Scotian Shelf to supplement the Canada C3 program sample collection") (Table 8).

Overall, net operations were successful during the mission. As with the CTD, net deployments occurred on the starboard side of the vessel, exposed to the wind and waves. This occasionally made operations technically difficult during inclement weather. Despite the challenges, the rate of unsuccessful tows was no more or less than typically experienced on our primary oceanographic platform (CCGS Hudson).

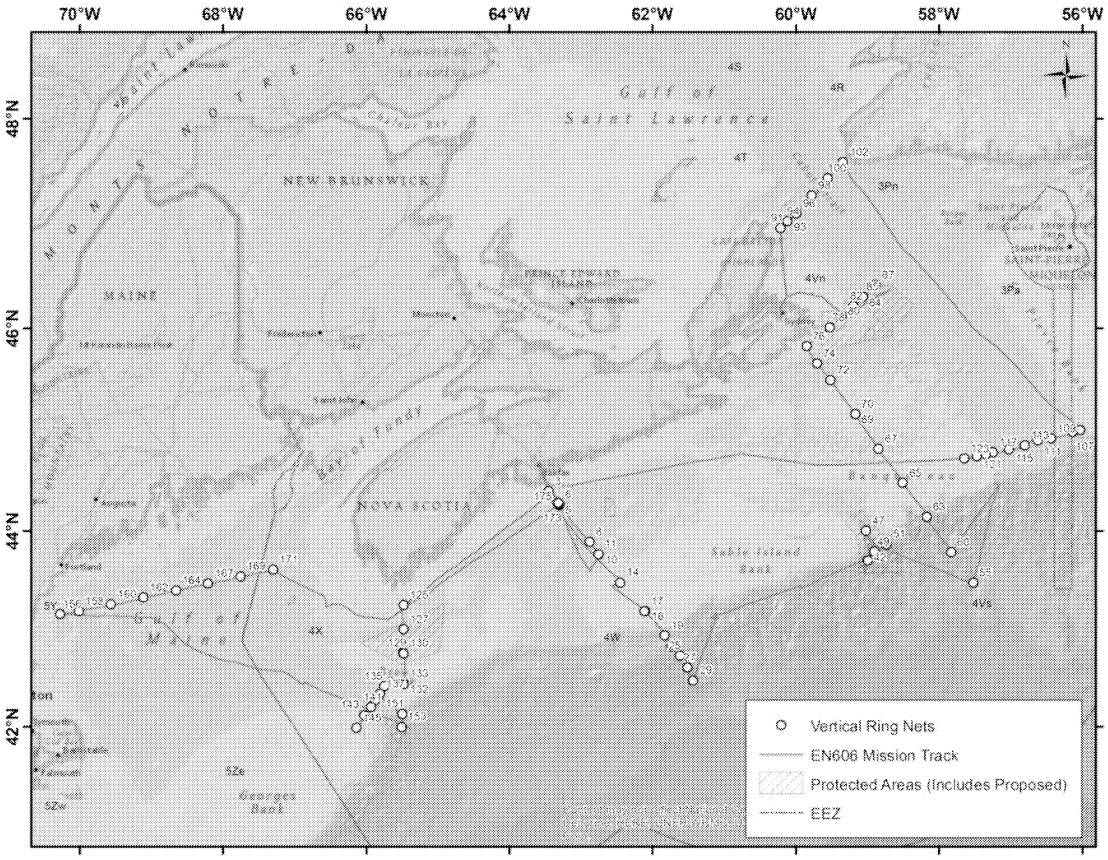


Figure 16. Locations for vertical ring net tows during EN2017606. Each tow is labelled with the consecutive mission event.

Table 8. Zooplankton collection activities during the EN2017606. The coordinates provided are in decimal degrees and reflect the ship's position at the time of deployment. Bold rows are tows that were aborted.

#	Event	Date	Station	Operation	Mesh Size (µm)	Slat (DD)	SLong (DD)	Objective	Comment
1	3	24/11/2017	HL_01	RingNet	202	44.3972	-63.4481	1	
2	5	25/11/2017	HL_02	RingNet	202	44.2625	-63.3086	1	
3	6	25/11/2017	HL_02	RingNet	76	44.2606	-63.3038	1	
4	8	25/11/2017	HL_03	RingNet	202	43.8854	-62.8836	1	
5	**10**	**25/11/2017**	**HL_03.3**	**RingNet**	**202**	**43.7644**	**-62.7546**		**Mud in sample aborted.**
6	11	25/11/2017	HL_03.3	RingNet	202	43.7645	-62.7519		No flow meter
7	14	27/11/2017	HL_04	RingNet	202	43.4780	-62.4524	1	
8	16	27/11/2017	HL_05	RingNet	202	43.1860	-62.1041	1	
9	17	27/11/2017	HL_05	RingNet	202	43.1877	-62.1099	13	C3 Gentics Sample
10	19	27/11/2017	HL_05.5	RingNet	202	42.9376	-61.8329		
11	**22**	**27/11/2017**	**HL_06**	**RingNet**	**202**	**42.8299**	**-61.7305**		**Lost sample.**
12	23	27/11/2017	HL_06	RingNet	202	42.8260	-61.7360	1	
13	25	28/11/2017	HL_06.3	RingNet	202	42.7313	-61.6202		Strong current.
14	**27**	**28/11/2017**	**HL_06.7**	**RingNet**	**202**	**42.6127**	**-61.5124**		**Lost sample, no reattempt.**
15	29	28/11/2017	HL_07	RingNet	202	42.4779	-61.4323	1	
16	**42**	**30/11/2017**	**SG_28**	**RingNet**	**202**	**43.7007**	**-58.9988**	**3**	**Wind gusts >40 kts on recovery and sample lost. No reattempt.**
17	47	01/12/2017	GULD_03	RingNet	202	43.9979	-59.0205	3	
18	49	01/12/2017	GULD_04	RingNet	202	43.7886	-58.9044	3	
19	51	01/12/2017	SG_23	RingNet	202	43.8629	-58.7335	3	
20	55	02/12/2017	LL_09	RingNet	202	43.4757	-57.5258	1	
21	60	02/12/2017	LL_08	RingNet	202	43.7835	-57.8365	1	
22	63	03/12/2017	LL_07	RingNet	202	44.1380	-58.1748	1	
23	65	03/12/2017	LL_06	RingNet	202	44.4769	-58.5101	1	

24	67	03/12/2017	LL_05	RingNet	202	44.8174	-58.8492	1	
25	69	03/12/2017	LL_04	RingNet	202	45.1611	-59.1737	1	
26	70	03/12/2017	LL_04	RingNet	202	45.1608	-59.1740	13	C3 Genetics Sample
27	72	03/12/2017	LL_03	RingNet	202	45.4910	-59.5173	1	
28	74	03/12/2017	LL_02	RingNet	202	45.6564	-59.7036	1	
29	76	03/12/2017	LL_01	RingNet	202	45.8246	-59.8521	1	
30	78	04/12/2017	STAB_01	RingNet	202	46.0039	-59.5323	10	
31	80	04/12/2017	STAB_02	RingNet	202	46.1109	-59.3656	10	
32	82	04/12/2017	STAB_03	RingNet	202	46.2163	-59.1955	10	
33	84	04/12/2017	STAB_04	RingNet	202	46.2997	-59.0652	10	
34	85	04/12/2017	STAB_04	RingNet	202	46.2994	-59.0655	13	C3 Genetics Sample
35	**87**	**04/12/2017**	**STAB_05**	**RingNet**	**202**	**46.4166**	**-58.8859**	**10**	**Mud in sample. No reattempt, continued with CTD then mooring.**
36	91	05/12/2017	CSL_01	RingNet	202	46.9602	-60.2187	1	
37	93	05/12/2017	CSL_02	RingNet	202	47.0240	-60.1161	1	
38	94	05/12/2017	CSL_02	RingNet	202	47.0246	-60.1165	13	C3 Genetics Sample
39	96	05/12/2017	CSL_03	RingNet	202	47.0995	-59.9906	1	
40	98	06/12/2017	CSL_04	RingNet	202	47.2715	-59.7780	1	Full stop at 188 m on descent. Full stop at 435 m on descent. ~2 kts of current, trying to reposition ship.
41	100	06/12/2017	CSL_05	RingNet	202	47.4351	-59.5585	1	
42	102	06/12/2017	CSL_06	RingNet	202	47.5829	-59.3393	1	
43	105	07/12/2017	BP_00	RingNet	202	45.0049	-56.0282	12	New station in 2017
44	107	07/12/2017	BP_01	RingNet	202	44.9784	-56.1396	12	
45	109	07/12/2017	BP_04	RingNet	202	44.9195	-56.4415	12	
46	111	08/12/2017	BP_05	RingNet	202	44.8968	-56.6252	12	
47	113	08/12/2017	BANQ_B6	RingNet	202	44.8485	-56.8035	12	
48	115	08/12/2017	BANQ_B5	RingNet	202	44.8078	-57.0256	12	

49	117	08/12/2017	BANQ_B4	RingNet	202	44.7811	-57.2509	12	
50	119	08/12/2017	BANQ_B3	RingNet	202	44.7609	-57.3473	12	
51	121	08/12/2017	BANQ_B2	RingNet	202	44.7439	-57.4776	12	
52	123	08/12/2017	BANQ_B1	RingNet	202	44.7205	-57.6525	12	
53	125	11/12/2017	BBL_01	RingNet	202	43.2492	-65.4810	1	
54	127	11/12/2017	BBL_02	RingNet	202	43.0019	-65.4796	1	
55	129	11/12/2017	BBL_03	RingNet	202	42.7590	-65.4821	1	
56	130	11/12/2017	BBL_03	RingNet	202	42.7562	-65.4780	13	C3 Genetics Sample
57	132	12/12/2017	BBL_04	RingNet	202	42.4467	-65.4805	1	
58	133	12/12/2017	BBL_04	RingNet	202	42.4423	-65.4768	13	C3 Genetics Sample
59	135	12/12/2017	PS_01	RingNet	202	42.4153	-65.7431	4	
60	137	12/12/2017	PS_02	RingNet	202	42.3373	-65.8070	4	
61	139	12/12/2017	PS_04	RingNet	202	42.2735	-65.8742	4	
62	141	12/12/2017	PS_06	RingNet	202	42.2006	-65.9350	4	2.5 kts of current during tow
63	143	12/12/2017	PS_08	RingNet	202	42.1192	-66.0328	4	
64	145	12/12/2017	PS_10	RingNet	202	41.9893	-66.1331	4	
65	151	12/12/2017	BBL_05	RingNet	202	42.1350	-65.4997	1	
66	153	13/12/2017	BBL_06	RingNet	202	41.9981	-65.5062	1	
67	156	14/12/2017	YL_10	RingNet	202	43.1563	-70.2715	4	
68	158	14/12/2017	YL_09	RingNet	202	43.1858	-70.0104	4	
69	160	14/12/2017	YL_08	RingNet	202	43.2561	-69.5605	4	All stop at 160 m on descent because the cable was under the ship.
70	162	15/12/2017	YL_07	RingNet	202	43.3246	-69.1090	4	
71	164	15/12/2017	YL_06	RingNet	202	43.3952	-68.6539	4	
72	167	15/12/2017	YL_05	RingNet	202	43.4683	-68.2044	4	
73	169	15/12/2017	YL_04	RingNet	202	43.5408	-67.7539	4	
74	171	15/12/2017	YL_03	RingNet	202	43.6059	-67.3007	4	
75	**173**	**16/12/2017**	**HL_02**	**RingNet**	**202**	**44.2693**	**-63.3164**	**1**	aborted
76	175	16/12/2017	HL_02	RingNet	202	44.2765	-63.3200	1	

Microbial Protein and Organic Micronutrient Sampling

Principle Investigator: Dr. Erin Bertrand (Dalhousie University, Department of Biology)
Sampling by: Jenni Tolman and Ian Luddington (Dalhousie University)

Objective
To collect underway and rosette samples for protein and vitamin analyses in order to determine whether and how organic and organometallic micronutrients influence primary productivity and phytoplankton community structure on the Scotian Shelf. Sampling locations were coordinated with the LaRoche lab since our data types are synergistically informative.

Microbial Protein Sampling

Purpose
Proteins are key to microbial activity: the type and amount of proteins present determines, in large part, the contributions microbes make to the ecosystems they occupy. Proteins can also be used as indices for nutritional status: elevated expression of specific proteins can be diagnostic for different nutritional states, such as nitrogen starvation, iron starvation, or vitamin starvation. Protein sequences also contain taxonomic information and can be used to assess contributions of different organisms to specific functions.

Samples were collected for targeted, mass spectrometry- based proteomic analyses of microbial communities in order to characterize the role of organic micronutrients in structuring phytoplankton communities on the Scotian Shelf. Primary objectives include measuring phytoplankton nutritional status indicator proteins (nitrogen, vitamin B_{12}, vitamin B_1 starvation) and vitamin- production biomarker proteins. Development and application of peptides for primary producer community composition analyses is a secondary focus.

Sampling Methods
A total of 31 size- fractionated microbial protein samples (10L of water each) were taken from the CTD rosette at depths ranging from the surface to 250 m depth (Table 9) along the Halifax and Louisburg Lines, and in the Gully. In each case, water was pre-filtered (330 μm) while dispensing from the Niskin bottle into 10L carboys. Water was then filtered through 3 and 0.2 μm polycarbonate filters via peristaltic pumping. Filters were then frozen immediately at -80°C.

Vitamin Sampling

Purpose
To determine the particulate and dissolved concentrations of organic and organometallic micronutrients on the Scotian Shelf. Organic and organometallic micronutrients are required by many phytoplankton groups and only produced by a select few microbes, setting up a series of interactive dependencies between microbial groups. The importance of these dependencies are not well known, as they have not yet been studied on the Scotian Shelf. Measuring the concentrations of these micronutrients in the particulate

and dissolved phases is one step towards understanding the role of microbial interactions in driving primary productivity and phytoplankton community structure.

Sampling Methods

A total of 31 particulate and 23 dissolved vitamin samples (1L each) were taken from the CTD rosette at depths ranging from the surface to 250 m depth along the Halifax, Gully, and Louisburg lines (Table 9). Samples were protected from light and gently vacuum filtered through 0.2 µm nylon filters. Filters were frozen at -80°C and dissolved samples were frozen in amber HDPE bottles at -20°C.

Table 9. Protein and vitamin sampling, Bertrand Lab EN2017606.

Station	Event	Depth (m)	ID#	Protein	Particulate Vitamin	Dissolved Vitamin
HL_02	7	1	444635	-	-	-
		20	444629	-	-	-
		40	444624	-	-	-
		80	444618	-	-	-
HL_04	15	1	444675	1	1	1
		20	444670	1	1	1
		40	444666	1	1	1
		60	444662	1	1	1
HL_06	24	1	444721	1	1	1
		20	444716	1	1	1
		50	444712	1	1	1
		80	444707	1	1	1
HL_07	30	1	444781	1	1	1
		20	444777	1	1	1
		50	444772	1	1	1
GULD_04	50	1	444832	1	1	-
		20	444827	1	1	-
		40	444823	1	1	-
		60	444820	1	1	-
LL_09	56	1	444870	1	1	1
		20	444866	1	1	1
		80	444858	1	1	1
		250	444854	1	1	1
LL_07	64	1	444908	1	1	-
		20	444903	1	1	-
		80	444896	1	1	-
		250	444891	1	1	-
LL_04	71	1	444946	1	1	1
		20	444940	1	1	1

		40	444936	1	1	1
		80	444932	1	1	1
LL_01	77	1	444986	1	1	1
		20	444981	1	1	1
		40	444977	1	1	1
		60	444973	1	1	1

Microbial Community Analysis

Principle Investigator: Dr. Julie LaRoche (Dalhousie University)
Sampling by: Jenni Tolman and Ian Luddington (Dalhousie University)

Purpose

Microbial communities and their associated processes are the foundation of marine life. Of particular interest to our group is the marine nitrogen cycle, comprising complex microbially-driven reactions whereby atmospheric nitrogen is fixed into a biologically-available form and cycled through the ecosystem. Though nitrogen is an essential element for life, the availability of fixed nitrogen can be a limiting factor for primary production and thus diazotrophs – organisms capable of biological nitrogen fixation – can be key to the productivity of an ecosystem.

Samples were collected for genomic and fluorescence-based analyses of the microbial communities on the Scotian shelf. Community composition will be assessed via 16S tag sequencing (bacteria and chloroplasts), and the naturally-fluorescent population will be characterized via flow cytometry. The latter method can also be used to quantify the bacterial community via nucleic acid stain SYBR green. Community function will be assessed via metagenomic sequencing, and qPCR assays for selected functional genes. Further samples were taken for manipulation in the lab, including targeted metagenomics and single cell isolation via fluorescence-associated cell sorting (FACS), and enrichment culturing of putative diazotrophs.

Sampling Methods

Genomics:

At 12 select stations along core AZMP lines (Halifax, Louisbourg, St Ann's Bank, and the Gully), duplicate 4L water samples were collected from the CTD rosette each of 4 depths ranging from the surface to 300 m (Table 10). During collection, water was pre-filtered through a 330 µm mesh to remove zooplankton. Each water sample was then sequentially filtered through 3 and 0.2 µm polycarbonate filters by peristaltic pump until the water was depleted or the filters clogged. Filters were immediately frozen at -80 °C. Samples have been collected at selected stations to provide time-series continuity with previous years (2014 and 2016).

Flow Cytometry:

At each station and depth where genomic samples were collected, duplicate 2mL water samples (330µm filtered) were fixed with 2% paraformaldehyde (PFA) for 10 minutes at room temperature, then frozen at -80°C for later enumeration of bacteria and characterization of the naturally fluorescent microbial community via the Accuri C6 flow cytometer.

At select stations (Table 10), 45 ml of 330 µm-filtered water were mixed with 5 ml of gly-TE buffer and frozen at -80 °C for later cell sorting on the BD Influx FACS instrument.

Enrichment Cultures:

At select stations (Table 10), large (1L) 330 µm-filtered water samples were collected. These samples were spiked with phosphate (200 nM) and iron (2 nM) and stored in conditions approximating natural light/dark cycles and ambient temperature until return to the lab.

Table 10. Microbial community samples, LaRoche lab EN2017606.

Station	Event	Depth (m)	ID#	DNA samples (size-fractionated)	Flow cytometry	Sorting Flow Cytometry	1L culture
HL_01	4	1	444613	2	2	-	-
		20	444609	2	2	-	-
		40	444605	2	2	-	-
		80	444603	2	2	-	-
HL_02	7	1	440574	2	2	-	-
		20	444630	2	2	-	-
		40	444625	2	2	-	-
		80	444619	2	2	-	-
HL_04	15	1	444676	2	2	-	-
		20	444671	2	2	-	-
		40	444667	2	2	-	-
		60	444663	2	2	-	-
HL_06	24	1	444720	2	2	-	-
		20	444717	2	2	-	-
		50	444711	2	2	-	-
		80	444708	2	2	-	-
HL_07	30	1	444782	2	2	-	-

		1	444779	-	-	1	1
		20	444776	2	2	-	-
		50	444773	2	2	-	-
		80	444769	2	2	-	-
GULD_04	50	1	444831	2	2	-	-
		20	444826	2	2	-	-
		60	444819	2	2	-	-
		250	444814	2	2	-	-
LL_09	56	1	444869	2	2	1	1
		20	444865	2	2	-	-
		80	444859	2	2	-	-
		250	444855	2	2	-	-
LL_07	64	1	444909	2	2	-	-
		20	444904	2	2	-	-
		80	444897	2	2	-	-
		250	444892	2	2	-	-
LL_04	71	1	444945	2	2	-	-
		20	444941	2	2	-	-
		40	444937	2	2	-	-
		80	444931	2	2	-	-
LL_01	77	1	444985	2	2	-	-
		20	444980	2	2	-	-
		40	444976	2	2	-	-
		60	444972	2	2	-	-
STAB_01	79	1	444998	2	2	-	-
		10	444995	2	2	-	-
		20	444993	2	2	-	-
		40	444990	2	2	-	-
STAB_05	88	1	445045	2	2	-	-
		20	445041	2	2	-	-
		80	445035	2	2	-	-
		300	445030	2	2	-	-

Pelagic Seabird and Marine Mammal Observations

Seabird Survey Report
Leg1: 24 Nov – 4 Dec, 2017
Canadian Wildlife Service, Environment Canada
Carina Gjerdrum carina.gjerdrum@ec.gc.ca
Observer: Jeannine Winkel

Background

The east coast of Canada supports millions of breeding marine birds as well as migrants from the southern hemisphere and northeastern Atlantic. In 2005, the Canadian Wildlife Service (CWS) of Environment Canada initiated the Eastern Canada Seabirds at Sea (ECSAS) program with the goal of identifying and minimizing the impacts of human activities on birds in the marine environment. Since that time, a scientifically rigorous protocol for collecting data at sea and a sophisticated geodatabase have been developed, relationships with industry and DFO to support offshore seabird observers have been established, and over 100,000 km of ocean track have been surveyed by CWS-trained observers. These data are now being used to identify and address threats to birds in their marine environment. In addition, data are collected on marine mammals, sea turtles, sharks, and other marine organisms when they are encountered.

Methods

Seabird surveys were conducted from the port side of the bridge of the Endeavor during the Scotian Shelf AZMP from 24 Nov to 4 Dec, 2017 (Leg 1). Surveys were conducted while the ship was moving at speeds greater than 4 knots, looking forward and scanning a 90° arc to one side of the ship. All birds observed on the water within a 300m-wide transect were recorded, and we used the snapshot approach for flying birds (intermittent sampling based on the speed of the ship) to avoid overestimating abundance of birds flying in and out of transect. Distance sampling methods were incorporated to address the variation in bird detectability. Marine mammal observations were also recorded, although surveys were not specifically designed to detect marine mammals. Details of the methods used can be found in the CWS standardized protocol for pelagic seabird surveys from moving platforms[1].

Results

Seabird sightings

We surveyed 628 km of ocean from 24 Nov to 4 Dec, 2017. A total of 878 birds were observed in transect (1259 birds in total) from 7 families (Table 11). Bird densities averaged 4.5 birds/km^2 (ranging from 0 – 88.5 birds/km^2). The highest densities of birds (> 50 birds/km^2) were observed on the Canso Bank and Western Banks (Figure 17A).

Dovekie accounted for 32% of the sightings (Table 11) and were scattered throughout the survey area (Figure 17B). The Scotian Shelf (and Grand Banks of NL) is an important wintering ground for Dovekie breeding in Greenland. Other Alcids observed in lower numbers include the Atlantic Puffin and Thick-billed Murre (Table 11). Northern fulmar and Black-legged Kittiwake were also relatively common (Table 11), especially in the deeper water (Northern Fulmar) and on the Canso Bank (Black-legged Kittiwake; Figure 17C). A complete list of all species observed can be found in Table 11.

Marine Mammal sightings

A total of 36 marine mammals were recorded during the surveys (Table 12), 86% of which were long-finned pilot whales, observed in the eastern sections of the survey (Figure 17D). A single Grey Seal was also identified.

Gully MPA

Surveys were conducted within the Gully MPA in the afternoon of 30 Nov and the following morning on 1 Dec. A total of 46 birds were observed and 16 marine mammals in this area (Table 13; Figure 18).

St. Anns Bank MPA

Surveys were conducted within the St. Anns Bank MPA in the morning and early afternoon of 4 Dec before steaming to the mouth of Sydney Harbor to end Leg 1. A total of 74 birds and 11 marine mammals (all long-finned pilot whales) were sighted here (Table 14 and Figure 19).

Table 11. List of bird species observed during surveys on the Scotian Shelf AZMP, from 24 Nov to 4 Dec, 2017.

Family	English	Latin	Number observed in transect	Total number observed
Procellariidae	Northern Fulmar	*Fulmarus glacialis*	204	215
	Great Shearwater	*Ardenna gravis*	0	1
Phalacrocoracidae	Unidentified Cormorant	*Phalacrocorax*	16	16
Sulidae	Northern Gannet	*Morus bassanus*	1	2
Anatidae	White-winged Scoter	*Melanitta fusca*	0	2
	Black Scoter	*Melanitta nigra*	1	1
	Unidentified Duck	All duck genera	0	7
Laridae	Great Skua	*Stercorarius skua*	0	1
	Unidentified Skua	*Stercorarius*	3	3
	Black-legged Kittiwake	*Rissa tridactyla*	197	228
	Herring Gull	*Larus argentatus*	83	102
	Great Black-backed Gull	*Larus marinus*	31	36
	Glaucous Gull	*Larus hyperboreus*	2	3
	Unidentified Gull	*Larus*	25	26
Alcidae	Dovekie	*Alle alle*	278	552
	Atlantic Puffin	*Fratercula arctica*	12	13
	Thick-billed Murre	*Uria lomvia*	10	10
	Unidentified Murre	*Uria*	0	10
	Unidentified Alcid	Alcidae	15	30
Emberizidae	Dark-eyed Junco	*Junco hyemalis*	0	1
Total			**878**	**1259**

Table 12. List of marine mammals observed during surveys on the Scotian Shelf AZMP, from 24 Nov to 4 Dec, 2017.

English	Latin	Total number observed
Long-finned Pilot Whale	*Globicephala melas*	31
Unidentified Cetaceans	Cetacea	1
Gray Seal	*Halichoerus grypus*	1
Unidentified Seals	Phocidae	3
Total		**36**

Table 13. List of species observed in the Gully Marine Protected Area during surveys on the Scotian Shelf AZMP, from 24 Nov to 4 Dec, 2017.

Species	Latin	Number observed in transect
Dovekie	*Alle alle*	14
Herring Gull	*Larus argentatus*	13
Black-legged Kittiwake	*Rissa tridactyla*	6
Northern Fulmar	*Fulmarus glacialis*	6
Great Black-backed Gull	*Larus marinus*	5
Unidentified Skua	*Stercorarius*	2
Long-finned Pilot Whale	*Globicephala melas*	15
Unidentified Cetaceans	Cetacea	1
Total sightings		**62**

Table 14. List of species observed in the St. Anns Bank Marine Protected Area during surveys on the Scotian Shelf AZMP, from 24 Nov to 4 Dec, 2017.

Species	Latin	Number observed in transect
Northern Fulmar	*Fulmarus glacialis*	24
Dovekie	*Alle alle*	23
Thick-billed Murre	*Uria lomvia*	10
Black-legged Kittiwake	*Rissa tridactyla*	9
Herring Gull	*Larus argentatus*	3
Great Black-backed Gull	*Larus marinus*	3
Glaucous Gull	*Larus hyperboreus*	2
Long-finned Pilot Whale	*Globicephala melas*	11
Total sightings		**85**

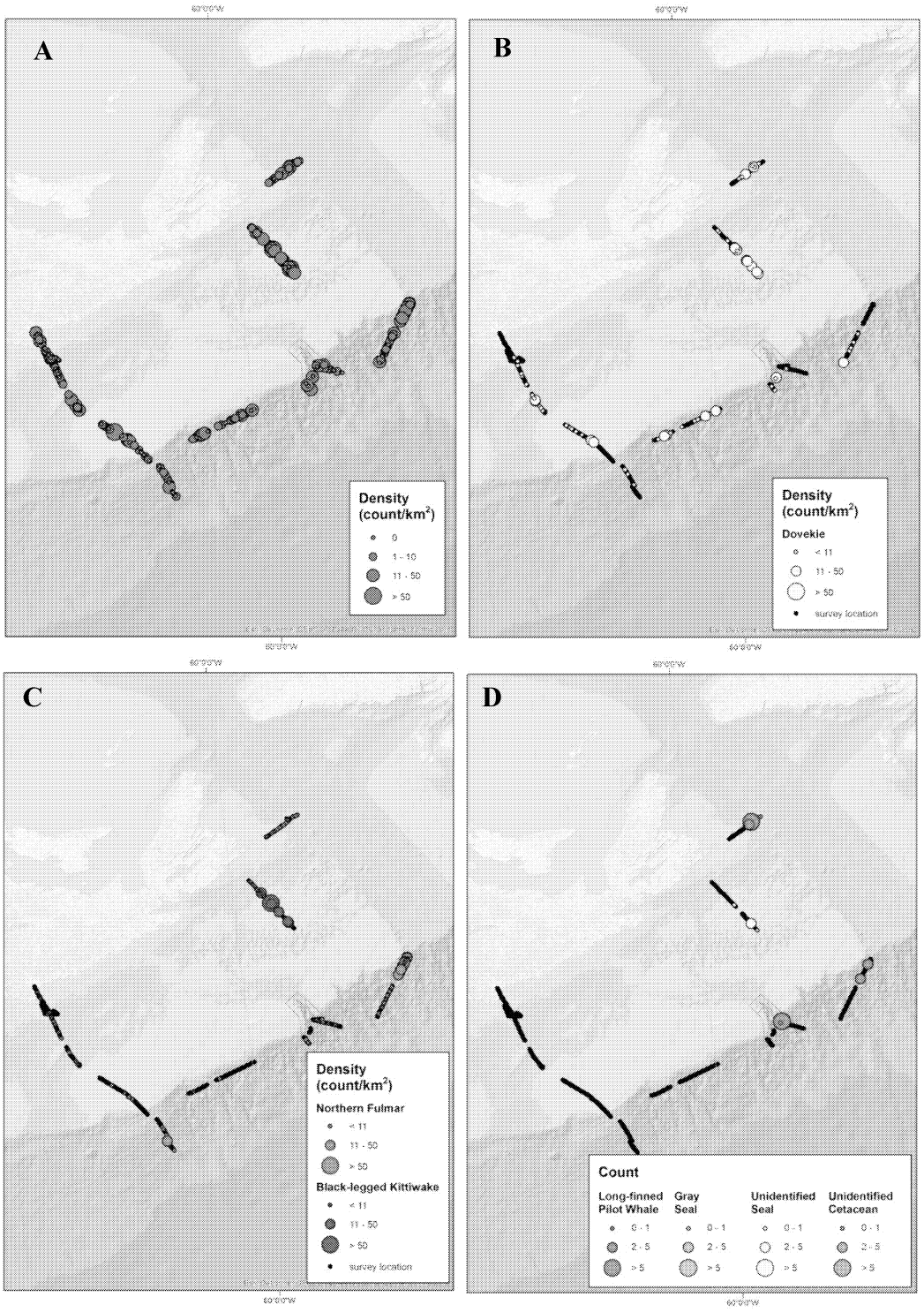


Figure 17. Density of A) all bird species combined, B) Dovekie, C) Northern Fulmar and Black-legged Kittiwake, and D) marine mammals observed during the seabird survey on the Scotian Shelf AZMP, from 24 Nov to 4 Dec, 2017.

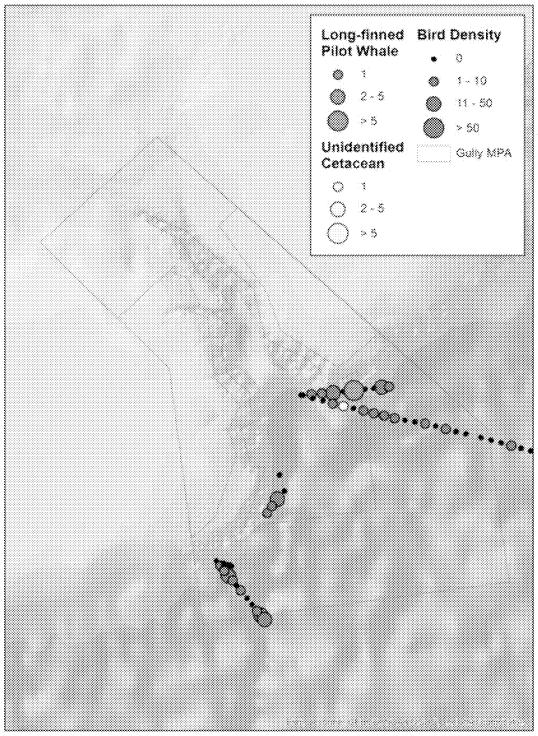


Figure 18. Density of birds and counts of marine mammals observed in the Gully Marine Protected Area on 30 Nov and 1 Dec, 2017.

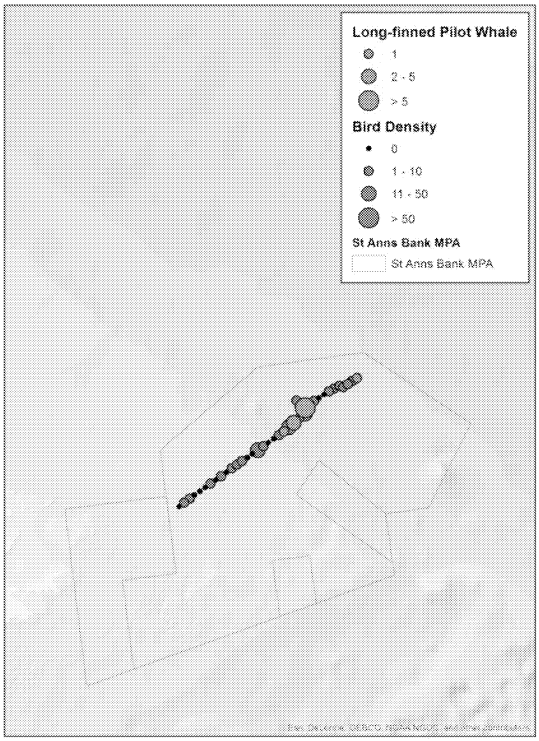


Figure 19. Density of birds and counts of marine mammals observed in the St. Anns Bank Marine Protected Area on 4 Dec, 2017.

ARGO Float Deployments

Contributions by: Ingrid Peterson

Narrative

There were a total of 6 APEX ARGO floats deployed during the mission (Figure 20 and Table 15). These floats continue to acquire data and their latest temperature profiles can be accessed on the following site by searching for their WMO numbers, 3901637-3901642 (Table 15). As of January 29th, 2018 the float profiles are not on the website but should be soon.

http://www.argodatamgt.org/Access-to-data/Description-of-all-floats2

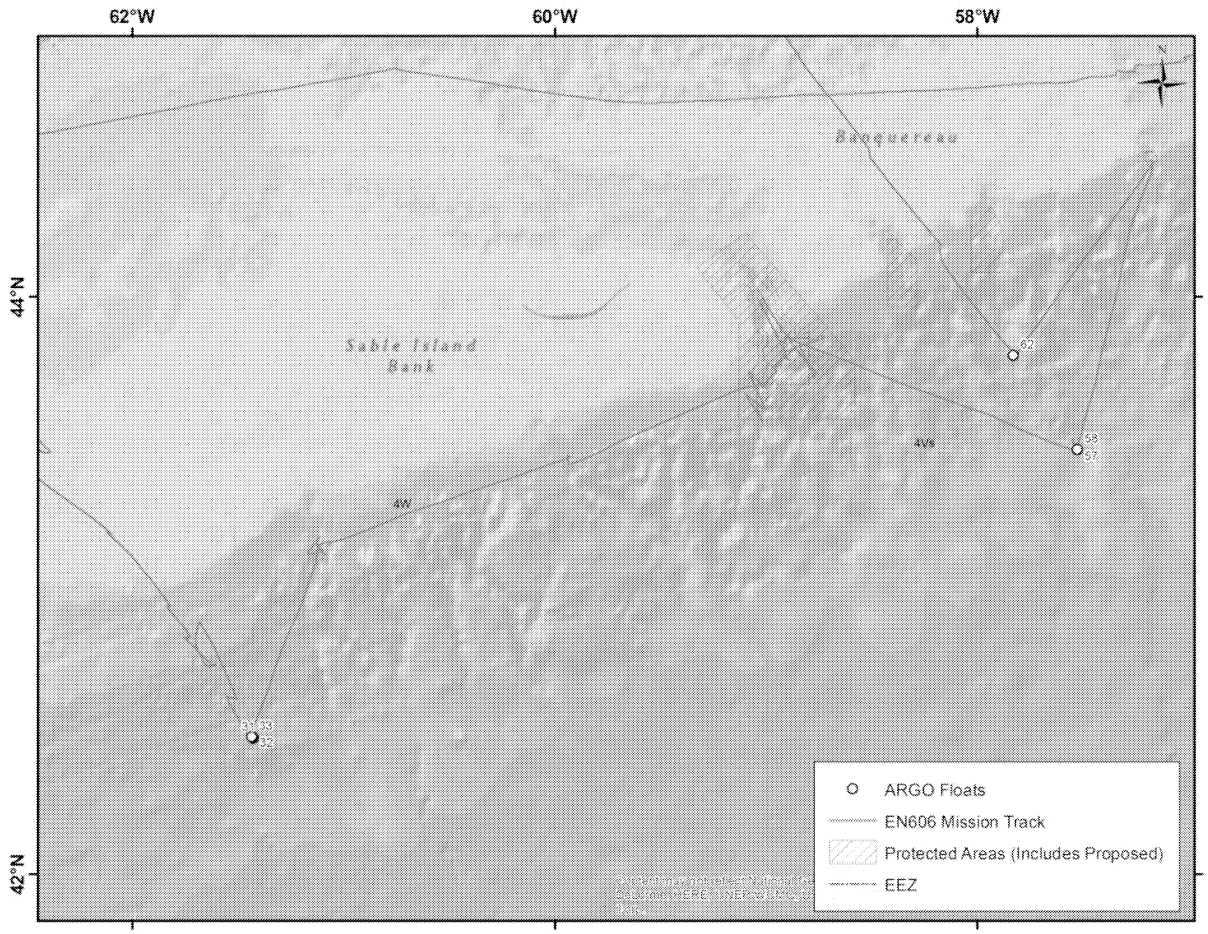


Figure 20. The locations for each Argo float deployment during EN2017606. Refer to Table 15 for more details.

Table 15. Details for Argo float deployments during EN2017606. The coordinates provided below are in decimal degrees and represent the ship's position at the time of deployment.

Date	Event	Station	Float Type	Float Deployed (UTC)	WMO #	S/N	Lat (DD)	Long (DD)
28/11/2017	31	HL_07	NOVA	23:00:23	3901641	8235	42.4764	-61.4296
28/11/2017	32	HL_07	NOVA	23:05:20	3901640	8237	42.4790	-61.4321
28/11/2017	33	HL_07	NOVA	23:09:29	3901637	8245	42.4813	-61.4339
02/12/2017	57	LL_09	NOVA	06:14:37	3901642	8234	43.4757	-57.5274
02/12/2017	58	LL_09	NOVA	06:19:06	3901639	8238	43.4754	-57.5280
02/12/2017	62	LL_08	NOVA	22:24:55	3901638	8239	43.7976	-57.8297

Mooring Operations

Contributions by: Jay Barthelotte

Narrative

Over the duration of the mission there were 5 moorings recovered and 6 deployed (Figure 21; Table 16). Please refer to Appendix 5 for the mooring diagrams. The Nova Scotia Current Mooring (M1996) was recovered on November 24th, and M2024 was deployed in its place on the same date and with the same sensor configuration. The first acoustic mooring (M1949) was recovered on November 25th from Emerald Basin and was not replaced.

After completing the occupation of HL_07 late on November 28th, we began the steam towards Dawson Canyon to deploy acoustic mooring (M2027). We arrived on site just after midnight on the 29th and spent the next ~ 7 hrs doing 5 CTD casts (DC_01 – DC_04) in close proximity to the planned mooring deployment location. At day break, M2027 was deployed and we began the steam towards Logan Canyon to deploy M2028 later in the afternoon of the 29th. This was followed by a CTD in close proximity (LC_01) before proceeding to the Gully MPA. After station SG_28 was occupied early in the morning of the 30th, acoustic release tests were conducted until early evening when M2026 was deployed in the Gully MPA. For the remainder of the 30th and overnight on December 1st, the remaining stations in the Gully were occupied before M1948 was recovered in the morning and then later replaced by M2025 at ~ the same location.

After completing Gully operations, the ship sailed towards the deep end of the Lousibourg Line (LL_09). After occupying LL_09 in the early morning of the 2nd, the ship began the steam towards the Lophelia Conservation Area to recover M1950 by mid-morning of the 2nd. After this recovery, the rest of the Louisbourg Line and all of the St. Anns Bank Line was occupied before deploying the final acoustic mooring (M2029) on the morning of December 4th. Later on the same day, the final acoustic mooring (M1947) was recovered.

It should be noted that the ADCP mooring (M1999) planned for recovery via dragging could not be contacted on the afternoon of December 4th and plans for dragging for the mooring were cancelled. After the mission we received information that parts of the mooring were discovered in Newfoundland on January 2nd, 2018.

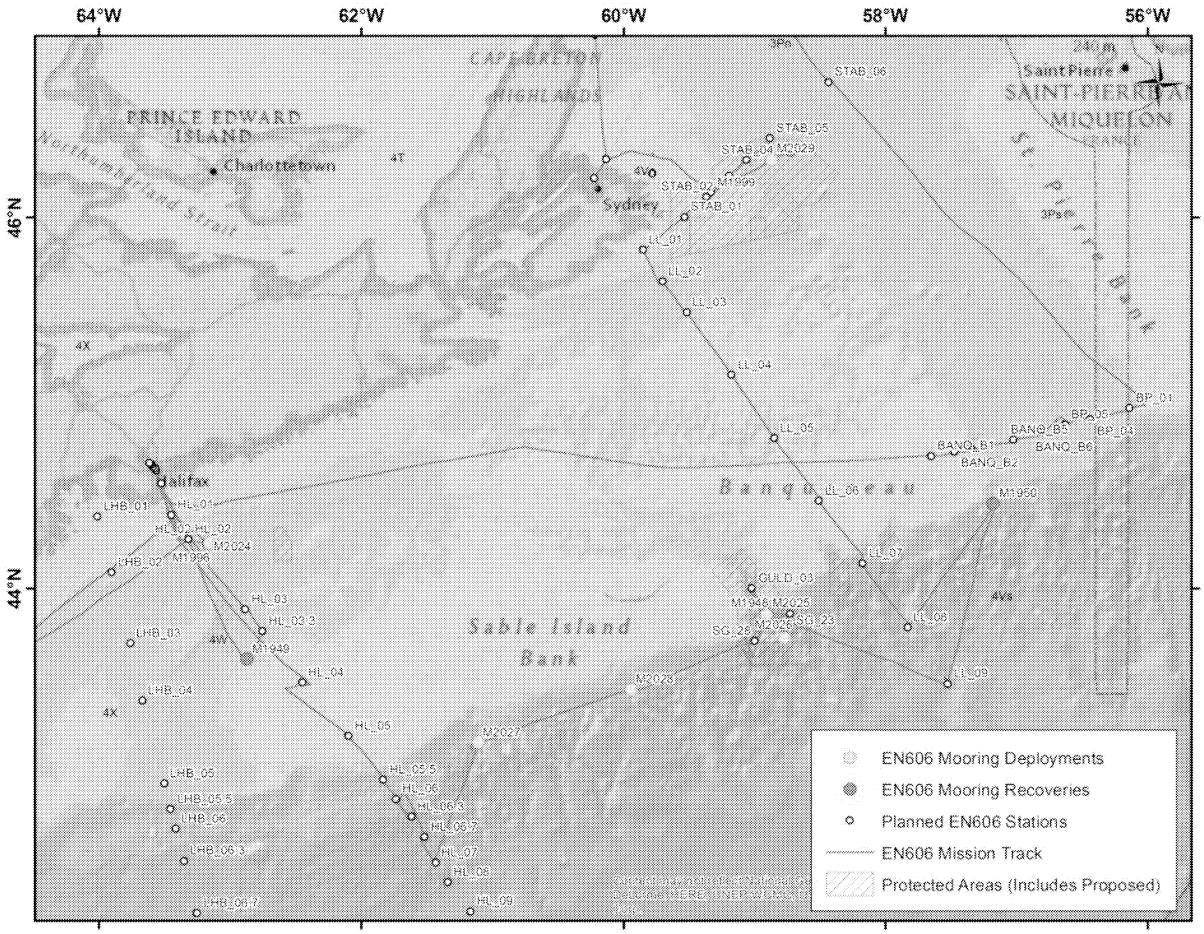


Figure 21. Mooring recovery and deployment locations during EN2017606.

Table 16. List of mooring operations during EN2017606. The coordinates provided below are in decimal degrees and represents the ship's position at the time of the operation.

Date	Event	Operation	Station	Slat (DD)	SLong (DD)	Program	Comments
24/11/2017	1	Recovery	M1996	44.2482	-63.1647	NSCM	Hebert
24/11/2017	2	Deployment	M2024	44.2455	-63.1631	NSCM	Hebert
25/11/2017	13	Recovery	M1949	43.6112	-62.8752	Acoustic	Moors-Murphy
27/11/2017	21	Release Test	HL_06	42.8302	-61.7287		
29/11/2017	39	Deployment	M2027	43.1500	-61.1104	Acoustic	Moors-Murphy
29/11/2017	40	Deployment	M2028	43.4424	-59.9428	Acoustic	Moors-Murphy
30/11/2017	44	Release Test	SG_28	43.7492	-58.9579		
30/11/2017	45	Release Test	SG_28	43.7567	-58.9669		
30/11/2017	46	Deployment	M2026	43.7306	-58.7739	Acoustic	Moors-Murphy
01/12/2017	53	Recovery	M1948	43.8620	-58.9135	Acoustic	Moors-Murphy

01/12/2017	54	Deployment	M2025	43.8583	-58.9107	Acoustic	Moors-Murphy
02/12/2017	59	Recovery	M1950	44.4647	-57.1838	Acoustic	Moors-Murphy
04/12/2017	89	Deployment	M2029	46.3044	-58.8742	Acoustic	Moors-Murphy
04/12/2017	90	Recovery	M1947	46.3562	-58.7306	Acoustic	Moors-Murphy

Underway Sampling

Contributions by: Robert Benjamin[1], Bill Fanning[2]
[1] Program Coordination and Support Division, DFO
[2] Marine Technician V, Endeavor, University of Rhode Island

Navigation

Positional data and Date/time ($GPGGA and $GPZDA) from the ship's GPS was logged throughout the mission along with sounding data from the ships EK60 scientific echo sounder ($SDDBT). Heading data ($HEHDT) was also logged. These data were logged at 1 Hz throughout the mission using NavNet, a data logging and distribution system designed by NRCAN. Prior to the ship's return to BIO, navigation data was converted into daily coordinate logs at 1 second intervals in both .csv and .shp formats.

The Endeavor's data logging systems where employed by the ships technician during the mission. This allowed logging of their TSG and ADCP systems internally and display of all systems where available during the mission including: ADCP, TSG, Wind direction and speed, Winch line-out and pressure, current position maps, and many on-board camera displays. A complete list of available sensors on the Endeavor can be found here: R:\Science\BIODataSvc\SRC\2010s\2017\EN606\Ship Deliverables\EN606_Hebert\scs\docs\sensor.html

Underway Seawater System

The Endeavor's underway seawater system was used throughout the mission. The configuration file for the Thermosalinograph (TSG) on EN2017606 can be found in Appendix 6.

Twenty-five gallons per minute is available from an intake located in the starboard sea chest, 48 feet from the bow. Seawater passes through a steel shut-off valve to a non-metallic pump. 1" PVC pipe to 1" PVC valves located in the Wet lab, 01 lab and on the 01 deck supply a constant flow for devices such as incubators. The water in the Wet lab flows through a debubbler to a low-pressure manifold suitable for supplying flow through instruments. The flow through instrumentation included a SBE 21 SEACAT Thermosaliograph (TSG), and SBE3S remote thermistor located near the water intake, a WetLabs WetStart Fluorometer and WetLabs Eco-AFL/FL.

Prior to sailing the underway system was also plummed to include a water bath housing a ProOceanus CO_2-Pro Atmosphere system to measure the partial pressure of CO_2.

Every day, a single PCO2 and TIC sample, along with 2 ChlA samples were acquired and provided with a unique sample ID. The scanned paper log for these samples will eventually be located here: R:\Science\BIODataSvc\SRC\2010s\2017\EN2017606\SCANNED_LOGS and the digital e-logs can be found here: R:\Science\BIODataSvc\SRC\2010s\2017\EN2017606\ELOG\Flow-Through Log. In total there were 21 PCO_2, 21 TIC and 42 Chla samples taken over this period.

All underway sea-water system data was submitted to ODIS upon conclusion of the mission. Dr. Dave Hebert Dave.Hebert@dfo-mpo.gc.ca) is the point of contact for these data.

Other Underway Data

The vessel also acquired a suite of underway measurements that are detailed on the Endeavor website. These data include vessel mounted ADCP, air temperature, humidity, wind speed and direction, barometric pressure, precipitation, short and long wave solar radiation and dual frequency (3.5 and 12 KHz) bathymetry. These data, as with all other data collected by ship provided equipment, were distributed to the DFO Data Manager and Chief Scientist upon the conclusion of the mission. They have been submitted to ODIS and can be found in the mission folder as specified in Appendix 7.

Data Management

Prepared by: Robert Benjamin
Division: Program Coordination and Support Division, DFO

Please refer to Appendix 7 for a table detailing the data collected during EN2017606.

Data Collection

In addition to standard AZMP manual data collection methods (i.e. various equipment specific deck sheets) ELOG, an electronic logbook system for collecting event metadata including position and sounding was used during EN2017606. This electronic logbook was accessible via computers connected to the RV Endeavor's network, including ship's data displays. Two locations in the main lab were used for data entry and one location in the Upper Lab for data Management. Metadata related to each piece of equipment was collected in the electronic log including position/time deployed, on bottom and recovered. Additional logbooks were employed to act as an itinerary, a daily operational log and a logbook to monitor the flow through. All digital logbooks were backed up daily and at the end of the mission were sent to ODIS for storage. After each event, the logbooks were entered into the Mission database.

CTD data was collected using the Endeavor's CTD system, setup and managed by the Endeavor data technician and backed up on the science server**.** After each CTD cast, the data was processed using CTDDAP and entered into the Mission database.

Nav-Net, an on board ship's data collection system was used to send data to Elog. In addition, Regulus was also used to record ship's data sent to the science team during the entire mission. These data will be located in the archive here:

R:\Science\BIODataSvc\SRC\2010s\2017\EN606\Nav

At the end of the mission, the Endeavors' data technician supplied a drive which contained all data collected by the vessel during the mission including TSG data. These data can be found here: R:\Science\BIODataSvc\SRC\2010s\2017\EN606\Ship Deliverables

NOTE: pC02 data was collected from the TSG system during the mission but NOT stored in SCS. These data will be stored here:

R:\Science\BIODataSvc\SRC\2010s\2017\EN606\pCo2

Salinity, Winkler Oxygen and Chlorophyll was analyzed while at sea. Data from the Analysis was routinely backed up and entered into the mission database.

Data Input Template

Reports were generated from shipboard input data in the AZMP Template Database to compare with corresponding CTD sensor data and conduct preliminary analyses included in this report.

GIS

Daily navigation and operations were maintained in a graphical information system (QGIS). Final line and point shapefile were generated from these data for the cruise report.

Hardware

One laptop was used to run the NavNet software. GPS data and Sounding data was sent to this computer via serial RS232 and logged. Data was transferred to our other computers via the ships network. The Endeavor's TSG system was used during the mission and data was saved in the ships SCS repository. pCo2 was collected in the Wet Lab along with the TSG.

APPENDICES

Appendix 1. Gully and St. Anns Bank MPA Activity Approvals

Gully Approval Signed Letter from RM

StAnnsMPA_EN2017606_approval.pdf

Fisheries and Oceans Canada / Pêches et Océans Canada

PO Box 1006
Dartmouth, NS
B2Y 4A2

File / Référence
GMPA-2015-05

Mr. Andrew Cogswell
Ocean and Ecosystem Sciences Division
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, NS B2Y 4A2

Dear Mr. Cogswell:

RE: Gully Marine Protected Area (MPA) Activity Approval
Atlantic Zone Monitoring Program 2015-2018

I am pleased to inform you that your request to collect seawater chemistry and zooplankton samples in the Gully MPA during Fall and Spring cruises of the Atlantic Zone Monitoring Program through October 2018 has been approved under Section 6(1) of the Gully MPA Regulations. Information provided in your 30 June application demonstrates compliance with the regulatory conditions that must be satisfied for Ministerial Approval. Any changes to the approved activities that have not been described in the submitted plan must be discussed with the Oceans and Coastal Management Division (OCMD) prior to commencement.

While in the MPA, you will be expected to comply with all applicable federal legislation. In particular, we'd like to emphasize that holding a Ministerial Approval issued pursuant to the *Gully MPA Regulations* and the *Oceans Act* does not satisfy the requirements of the *Species at Risk Act* or the *Fisheries Act*. Neither does the MPA Approval given here substitute for any permits or licences required under those statutes. It is your responsibility to ensure any necessary authorizations are acquired prior to undertaking the approved MPA activities. Further, you are expected to comply fully with any conditions stipulated therein.

To support conservation and protection of the MPA ecosystem, you are asked to adhere to the following requests while undertaking the approved research:

1. Maintain a watch during daylight hours for marine mammals as described in the submitted Activity Plan. Record those observations and any sightings of turtles and marine debris (e.g., abandoned fishing gear, plastics, other garbage or pollutants). Provide sightings information to Oceans and Coastal Management Division (OCMD).

Canada

../2

2. Report environmental emergencies or other incidents, including unintentional discharges and mammal collisions, to the Canadian Coast Guard within two hours of the occurrence. Notify OCMD as soon as possible and file an incident report.
3. Provide an activity report to OCMD that details MPA arrival and departure dates & times, and outlines operations undertaken within the MPA.

We have enclosed a set of templates and instructions to assist with the documentation being sought in the requests attached to this Approval. The activity report, sightings data, and incident notifications should be submitted to Tanya Koropatnick in OCMD. Please feel free to follow-up with Tanya should you have any questions or need further clarification:

Tanya Koropatnick
Fisheries and Oceans Canada
Bedford Institute of Oceanography
1 Challenger Dr., B500
Dartmouth, NS
B2Y 2V9

Phone: (902) 426-6048
E-mail : Tanya.Koropatnick@dfo-mpo.gc.ca

Thank you for your continued interest in the Gully MPA. The bi-annual AZMP sampling program contributes data to the ecological knowledge base and is directly linked to the site's long-term monitoring needs. Your AZMP trips also provide a consistent and predictable platform for the conduct of other important research and monitoring activities. OCMD remains grateful for this ongoing Science Branch support and welcomes the AZMP for another 3 years of sampling in the Gully MPA.

Yours sincerely,

G. Herbert

Glen Herbert
A/Regional Manager
Oceans and Coastal Management Division
Ecosystem Management Branch
Maritimes Region

Attachments: Approved Activity Plan
Activity and Incident Report Template

Fisheries and Oceans Canada / Pêches et Océans Canada

PO Box 1006
Dartmouth, NS
B2Y 4A2

File / Référence
SABMPA-2017-10

Andrew Cogswell
Bedford Institute of Oceanography
1 Challenger Dr
Dartmouth, NS
B2Y 4A2

Dear Mr. Cogswell:

RE: St. Anns Bank Marine Protected Area (MPA) Activity Approvals

I am pleased to inform you that your request to conduct the Atlantic Zone Monitoring Program (AZMP) in the St. Anns Bank Marine Protected Area (MPA) has been approved under section 10(1) of the *St. Anns Bank MPA Regulations*. Based on the information you submitted on October 5, 2017, Fisheries and Oceans Canada (DFO) has determined that your activity meets the regulatory conditions required for issuance of Ministerial Approval.

We will anticipate your advance notices before sailing under any vessel used. Any changes to the approved activities that have not been described in the information submitted must be discussed with the Oceans and Coastal Management Division (OCMD) prior to commencement. Approval renewals for future years are subject to reassessment.

While in the MPA, you will be expected to comply with all applicable legislation. In particular, we would like to emphasize that holding a Ministerial Approval issued pursuant to the *St. Anns Bank MPA Regulations* under the *Oceans Act* does not satisfy the requirements of the *Species at Risk Act* or the *Fisheries Act*. Neither does the MPA Approval given here substitute for any permits or licences required under those statutes. It is your responsibility to ensure any necessary authorizations are acquired prior to undertaking the approved MPA activities.

As per Section 11 of the *St. Anns Bank MPA Regulations*, a post-activity report on the activity conducted in the MPA is required 90 days following the completion of the activity. We will contact you shortly with more details on what is required for reporting.

Vessels must comply with all relevant provisions of the Marine Mammal Regulations pursuant to the *Fisheries Act*. Further guidance for vessel operation can be found in Section A2 of the Annual Notices to Mariners (***Marine Mammal Guidelines and Marine Protected Areas)*** as published by the Canadian Coast Guard (https://www.notmar.gc.ca).

To support conservation and protection of the MPA ecosystem, you are asked to adhere to the following requests while undertaking the approved research:

1. Maintain a watch during daylight hours for turtles, marine mammals and marine debris (e.g., abandoned fishing gear, plastics, other garbage or pollutants).

.../2

2. Report any marine mammal collisions, entanglements, distressed or dead animals to the Marine Animal Response Society's emergency hotline (1-866-567-6277), or via VHF channel 16. Sightings of healthy marine mammals should be reported to XMARwhalesightings@dfo-mpo.gc.ca. The following information about the sightings should be included: date, time, location and species. Photos and videos should be submitted if available.

3. Report all live and dead sea turtle sightings and incidents (e.g., entanglements, collisions) to the Canadian Sea Turtle Network's hotline (1-888-729-4667) or online at http://seaturtle.ca/turtle-sighting/. The following information about the sighting or incident should be included: date, time, location, species, and condition of the animal. Photos and videos should be submitted if available.

4. Report environmental emergencies or other incidents, such as unintentional discharges, to the Canadian Coast Guard within two hours of the occurrence. Notify OCMD as soon as possible and file an incident report.

Once completed, the activity report and incident notifications should be submitted to Melanie MacLean in OCMD at:

Melanie MacLean
Fisheries and Oceans Canada
Bedford Institute of Oceanography
1 Challenger Dr., B500
Dartmouth, NS
B2Y 2V9
Phone: (902) 440-5727
E-mail: melanie.maclean@dfo-mpo.gc.ca

Please confirm with Melanie MacLean that you have received this letter, and feel free to follow-up anytime should you have any questions or need further clarification.

Yours sincerely,

Wendy Williams
A/Director, Oceans Management
Oceans and Coastal Management Division
Ecosystem Management Branch
Fisheries and Oceans Canada, Maritimes Region

Appendix 2. Crew List for the R/V Endeavor 606.

CREW LIST
AMERICAN OCEANOGRAPHIC RESEARCH MOTOR VESSEL

R/V ENDEAVOR

IMO Number: 7604300
Registration: RI-59A

HOME PORT: NARRAGANSETT, RI, USA

No	Family Name	Fore Name(s)	Position	Seaman's Passport & Expire Date	Date of Birth/Gender	Citizen
1	CARTY	Paul F.	Master			USA
2	ARMANETTI	Christopher P.	Mate			USA
3	THORNTON	Brendan E.	Mate			USA
4	SISSON	Steven A.	Boatswain			USA
5	MAYNE	John P.	Able Seaman			USA
6	BUELL	Patrick J.	Able Seaman			USA
7	WALSH	Kevin D.	Able Seaman			USA
9			Chief Engineer			
9			Asst. Engineer			
10			Asst. Engineer			
11	DUFFY	Michael J.	Steward			USA
12	GRUEBEL	Erich M.	Marine Tech			USA

Total Number of Crew: 12 including Master on Arrival
Dartmouth, Canada

Date: 16 December 2017

Cruise No. EN-606

16 DE 2017

Paul F. Carty
Master **R/V ENDEAVOR**

R/V ENDEAVOR
URI Graduate School Of Oceanography
PO Box 145
Saunderstown, RI 02874

Appendix 3. CTD Configuration File – EN606.xmlcon

Date: 01/17/2018

Instrument configuration file:
R:\Science\BIODataSvc\SRC\2010s\2017\EN606\CTD\CTD_PROCESSING\EN606\EN606.XMLCON

Configuration report for SBE 911plus/917plus CTD

Frequency channels suppressed : 0
Voltage words suppressed : 0
Computer interface : RS-232C
Deck unit : SBE11plus Firmware Version >= 5.0
Scans to average : 1
NMEA position data added : Yes
NMEA depth data added : No
NMEA time added : No
NMEA device connected to : deck unit
Surface PAR voltage added : Yes
Scan time added : No

1) Frequency 0, Temperature

Serial number : 2902
Calibrated on : 15-Dec-16
G : 4.34451712e-003
H : 6.44730310e-004
I : 2.28889365e-005
J : 2.12526223e-006
F0 : 1000.000
Slope : 1.00000000
Offset : 0.0000

2) Frequency 1, Conductivity

Serial number : 3220
Calibrated on : 16-Dec-16
G : -9.77555876e+000
H : 1.34416455e+000
I : -2.86467321e-005
J : 6.94809804e-005
CTcor : 3.2500e-006
CPcor : -9.57000000e-008
Slope : 1.00000000
Offset : 0.00000

3) Frequency 2, Pressure, Digiquartz with TC

Serial number : 0444
Calibrated on : 20-Dec-16
C1 : -5.378517e+004
C2 : -3.498580e-001
C3 : 1.648580e-002
D1 : 4.036100e-002
D2 : 0.000000e+000
T1 : 2.984744e+001
T2 : -3.538190e-004
T3 : 3.972770e-006
T4 : 2.922330e-009
T5 : 0.000000e+000
Slope : 0.99989692
Offset : -0.45761
AD590M : 1.125800e-002
AD590B : -8.763490e+000

4) Frequency 3, Temperature, 2

Serial number : 2034
Calibrated on : 13-Dec-16
G : 4.41249522e-003
H : 6.41293978e-004
I : 2.37750205e-005
J : 2.28693904e-006
F0 : 1000.000
Slope : 1.00000000
Offset : 0.0000

5) Frequency 4, Conductivity, 2

Serial number : 0864
Calibrated on : 15-Dec-16
G : -3.93005749e+000
H : 5.65787779e-001
I : -6.14331081e-004
J : 6.37838626e-005
CTcor : 3.2500e-006
CPcor : -9.57000000e-008
Slope : 1.00000000
Offset : 0.00000

6) A/D voltage 0, Transmissometer, WET Labs C-Star

Serial number : 969DR

Calibrated on : 06-Dec-16/15-Feb-17field
M : 19.5917
B : -1.1363
Path length : 0.250

7) A/D voltage 1, Fluorometer, WET Labs ECO-AFL/FL

Serial number : 492
Calibrated on : 15-Dec-16
Dark output : 0.0250
Scale factor : 2.40000000e+001

8) A/D voltage 2, Altimeter

Serial number : 49899
Calibrated on : 30-Mar-15
Scale factor : 15.000
Offset : 0.000

9) A/D voltage 3, PAR/Irradiance, Biospherical/Licor

Serial number : 70513
Calibrated on : 21-Nov-16
M : 1.00000000
B : 0.00000000
Calibration constant : 9900990099.00989910
Multiplier : 1.00000000
Offset : -0.10245222

10) A/D voltage 4, Oxygen, SBE 43

Serial number : 1230
Calibrated on : 02-Aug-17
Equation : Sea-Bird
Soc : 5.03470e-001
Offset : -5.15300e-001
A : -3.72370e-003
B : 2.04260e-004
C : -2.88240e-006
E : 3.60000e-002
Tau20 : 1.81000e+000
D1 : 1.92634e-004
D2 : -4.64803e-002
H1 : -3.30000e-002
H2 : 5.00000e+003
H3 : 1.45000e+003

11) A/D voltage 5, Oxygen, SBE 43, 2

Serial number : 0345
Calibrated on : 02-Aug-17
Equation : Sea-Bird
Soc : 3.82810e-001
Offset : -7.22200e-001
A : -4.10370e-003
B : 1.65940e-004
C : -2.39230e-006
E : 3.60000e-002
Tau20 : 1.24000e+000
D1 : 1.92634e-004
D2 : -4.64803e-002
H1 : -3.30000e-002
H2 : 5.00000e+003
H3 : 1.45000e+003

12) A/D voltage 6, pH

Serial number : 1307
Calibrated on : 03-Feb-17
pH slope : 4.6258
pH offset : 2.5383

13) A/D voltage 7, Fluorometer, WET Labs ECO CDOM

Serial number : 3745
Calibrated on : 23-Nov-2017
Dark output : 0.000
Scale factor : 3.000

14) SPAR voltage, Unavailable

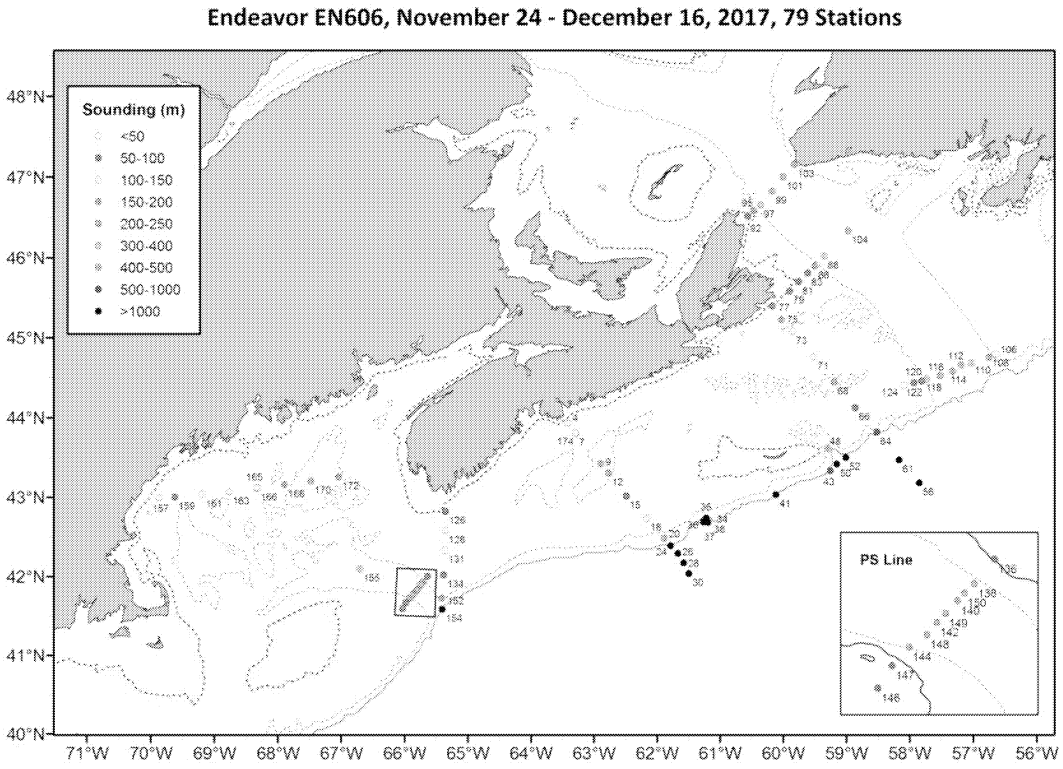
15) SPAR voltage, SPAR/Surface Irradiance

Serial number : 20190
Calibrated on : 21-Nov-16
Conversion factor : 1565.10000000
Ratio multiplier : 1.00000000

Scan length : 40

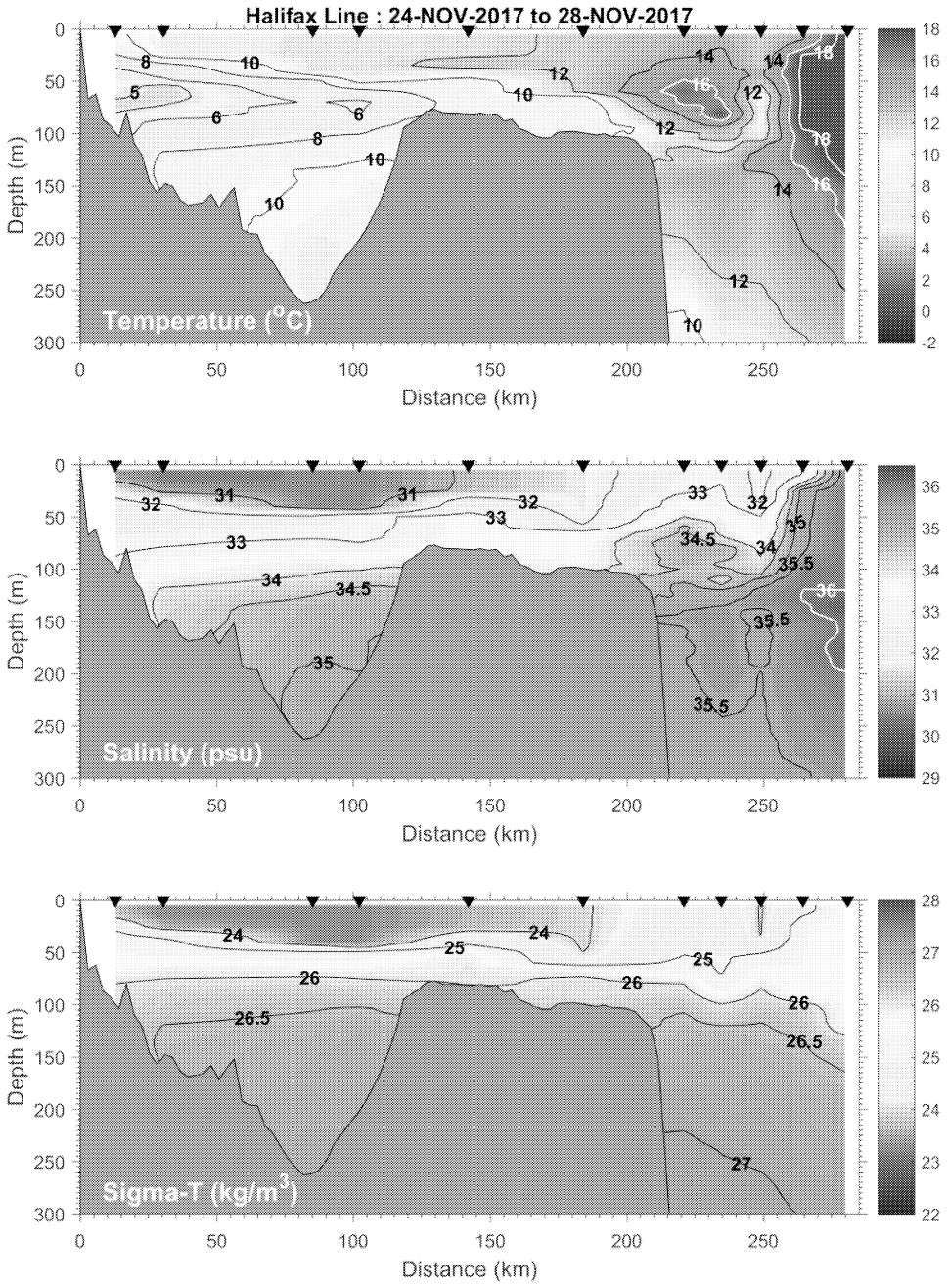
Appendix 4. Preliminary Section Plots and Anomalies (T/S/Sigma-T)

Section plots were produced for Temperature, Salinity and Sigma-T all sections from EN606 (See map below). It should be noted that no anomalies were produced because this mission was well outside of the typical sailing dates for most of the preceding fall AZMP missions. Finally, BBL_07 was not occupied during the mission as noted in the mission narrative.



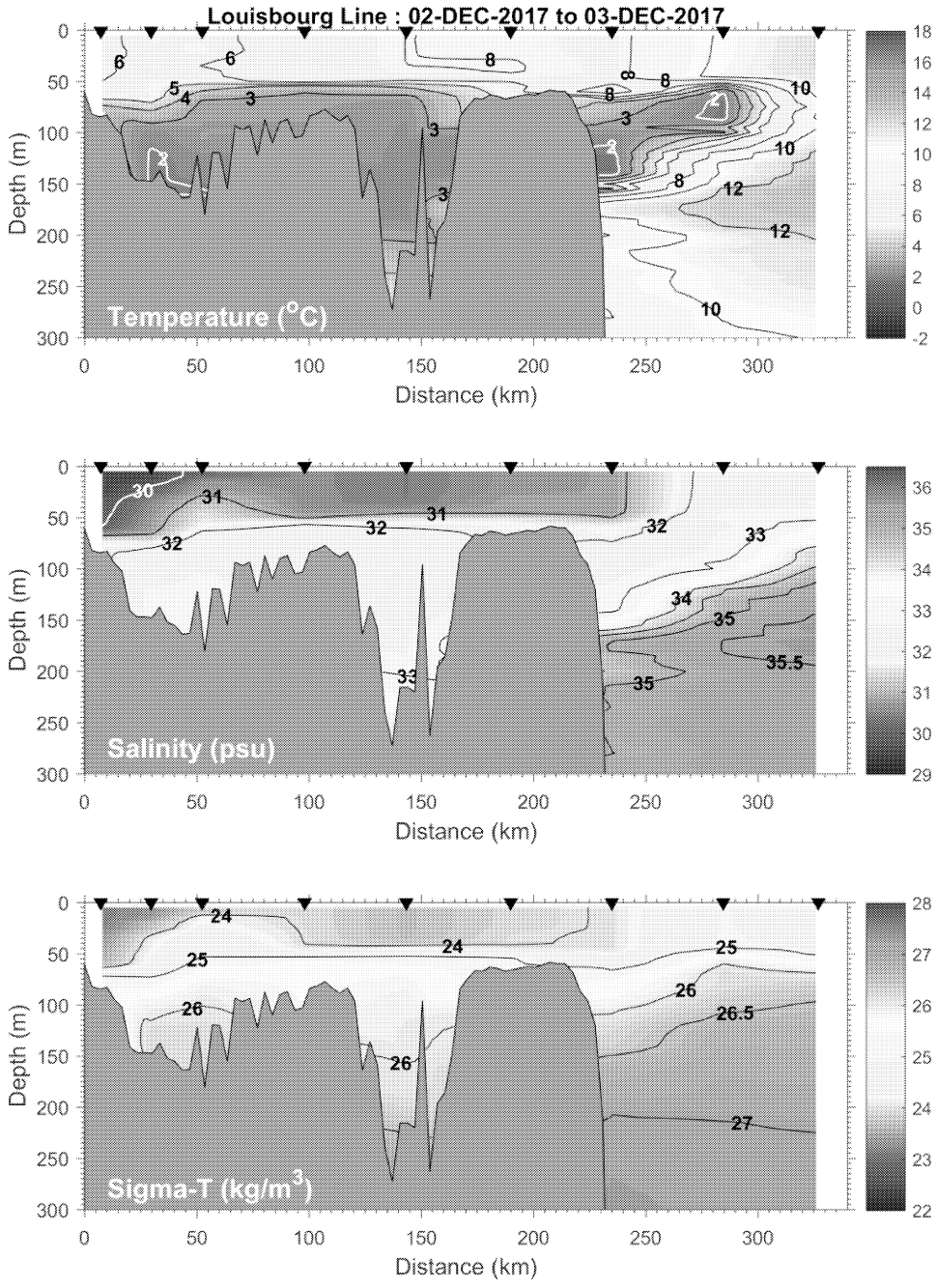
Halifax Line

Section



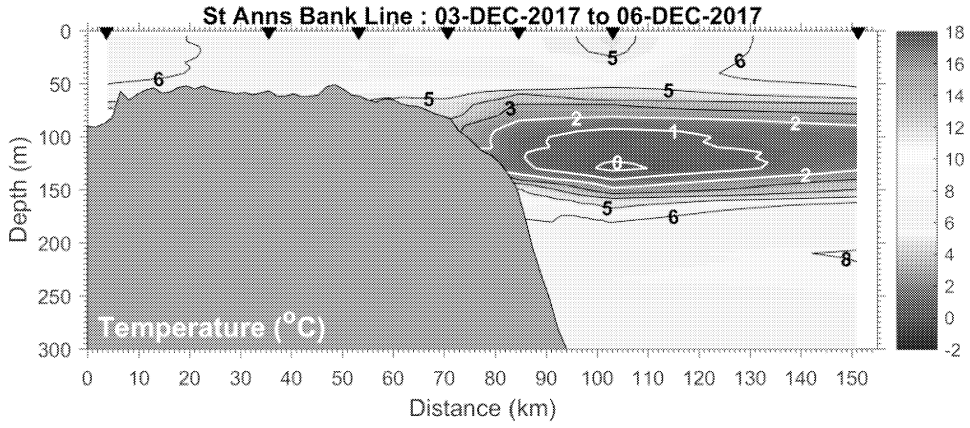
Louisbourg Line

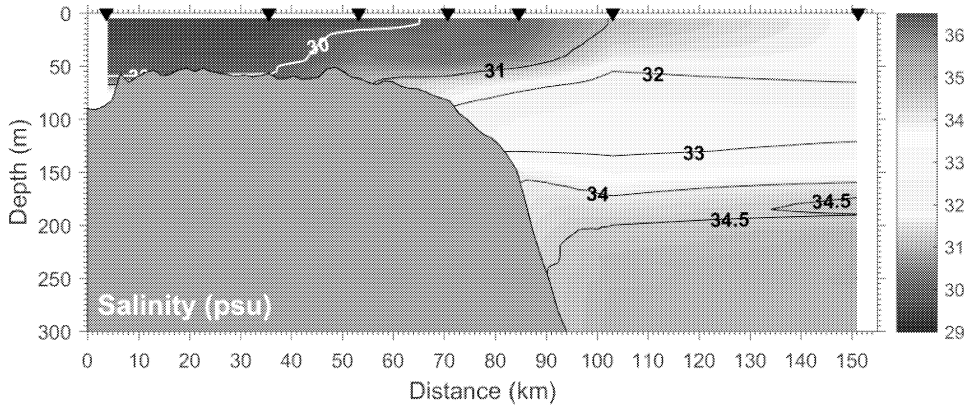
Section

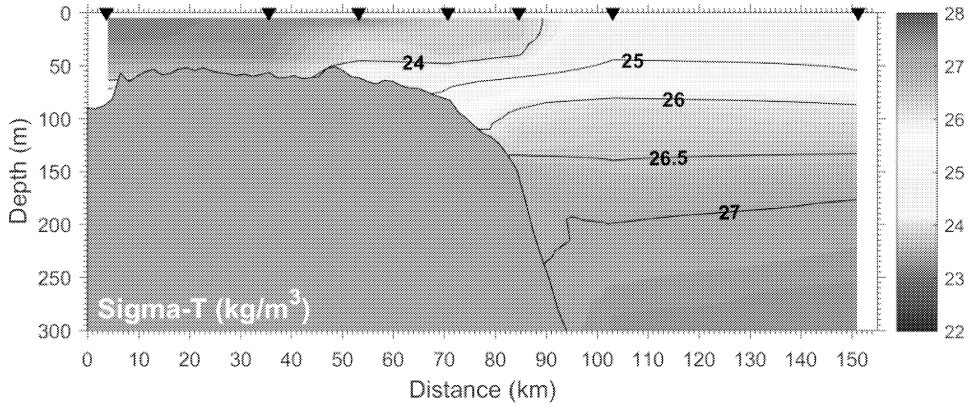


St. Anns Bank Line

Section

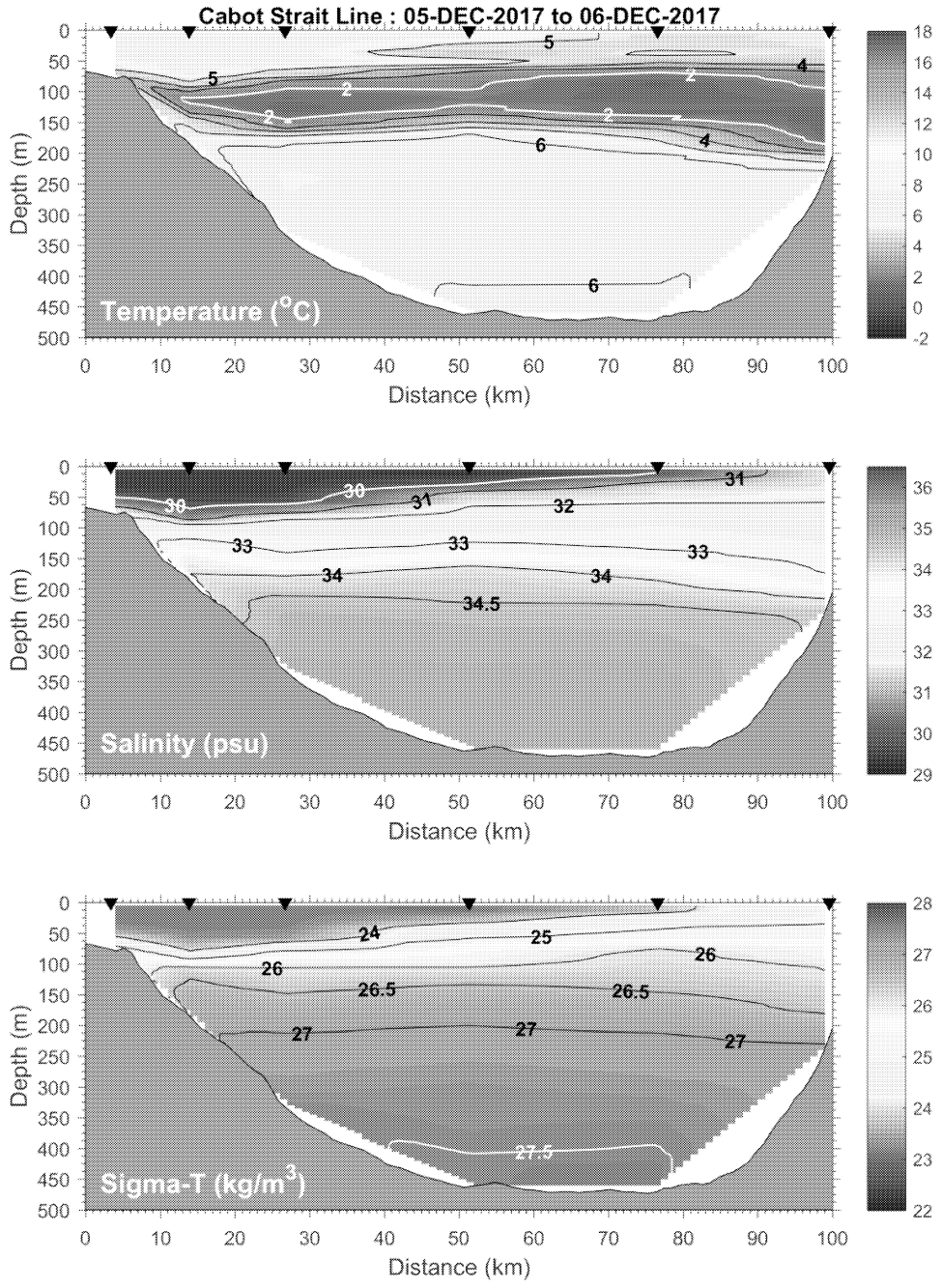






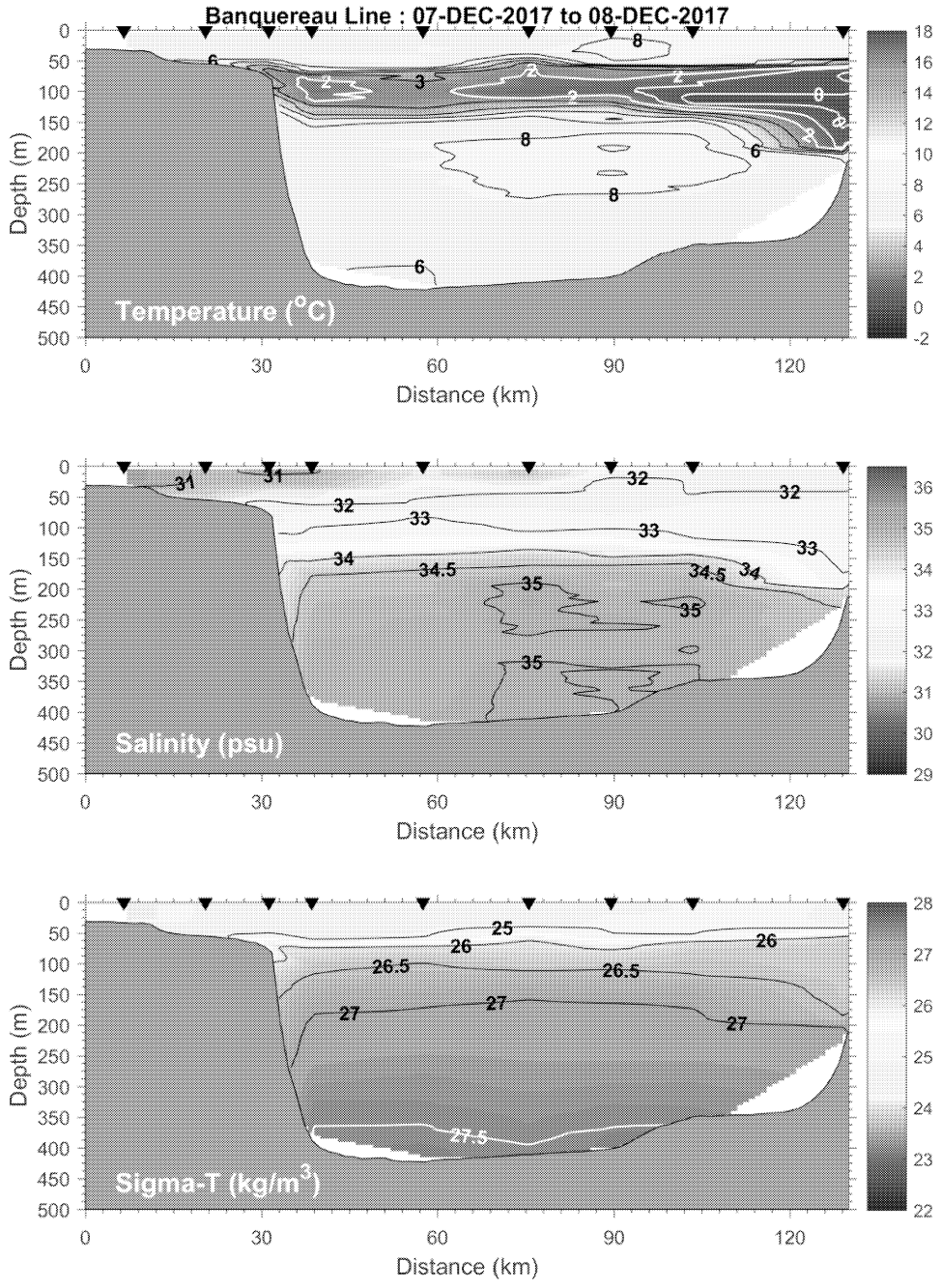
Cabot Strait Line

Section



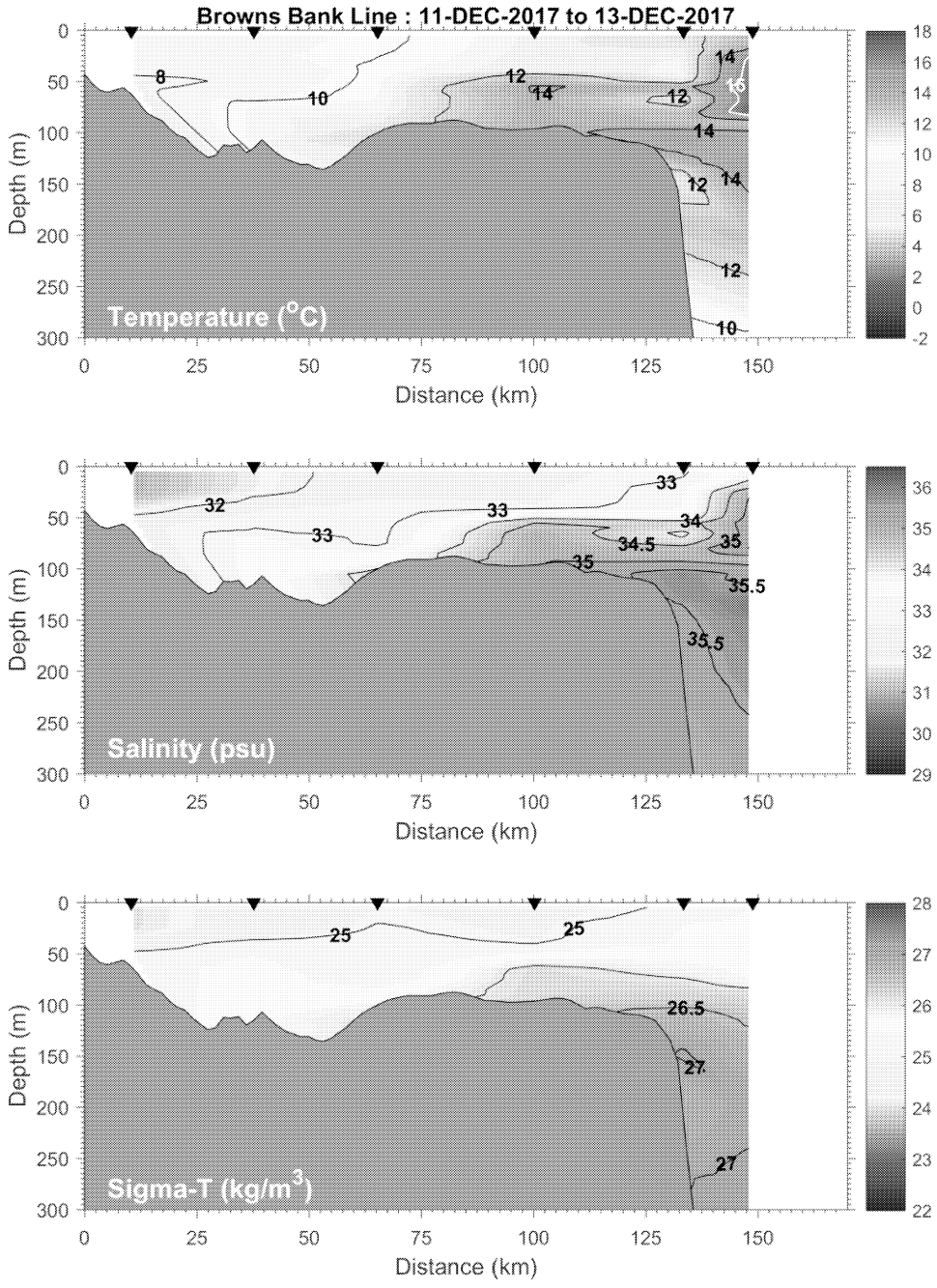
Brian Petrie/Banquereau Line

Section



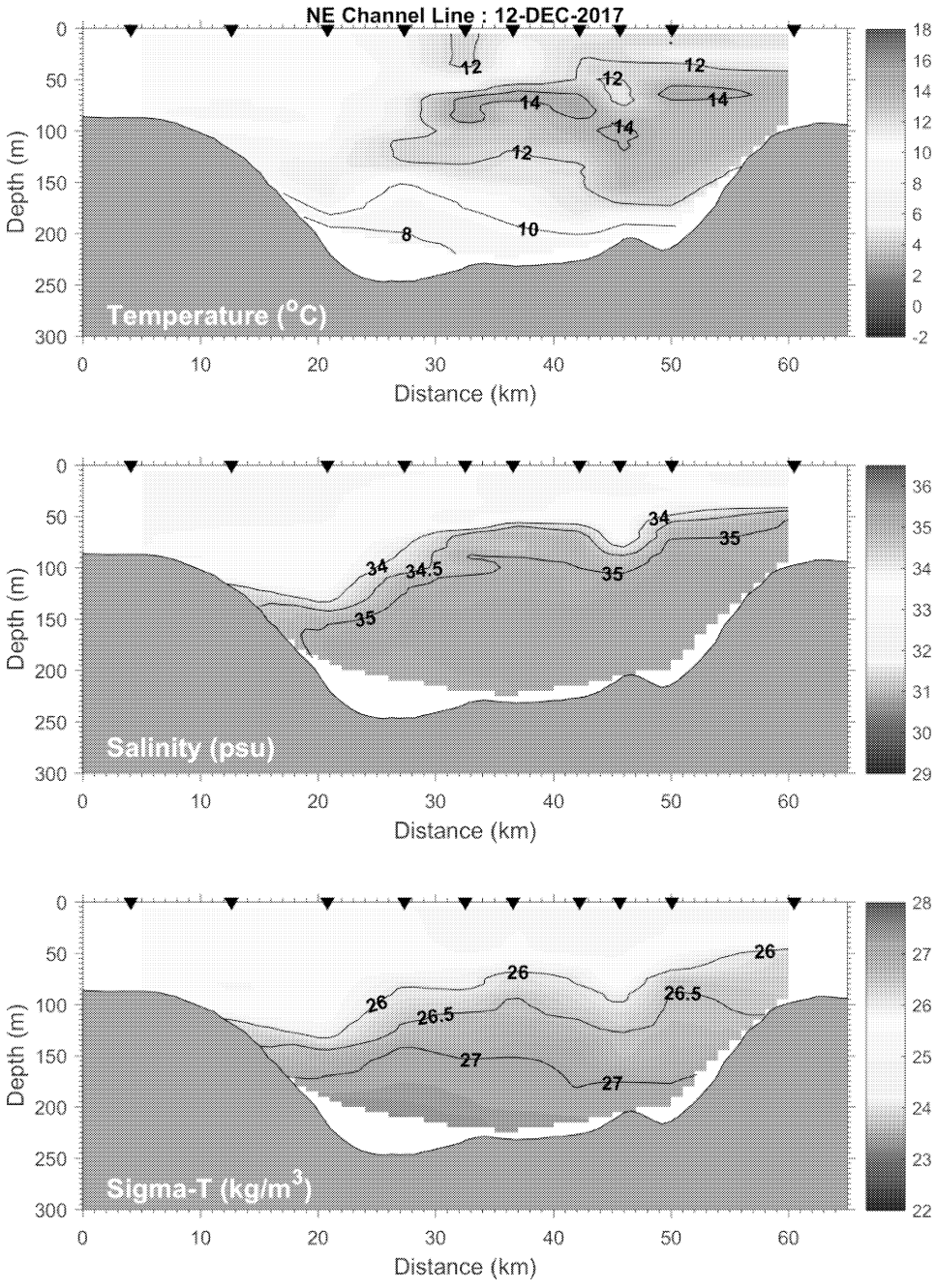
Browns Bank Line

Section



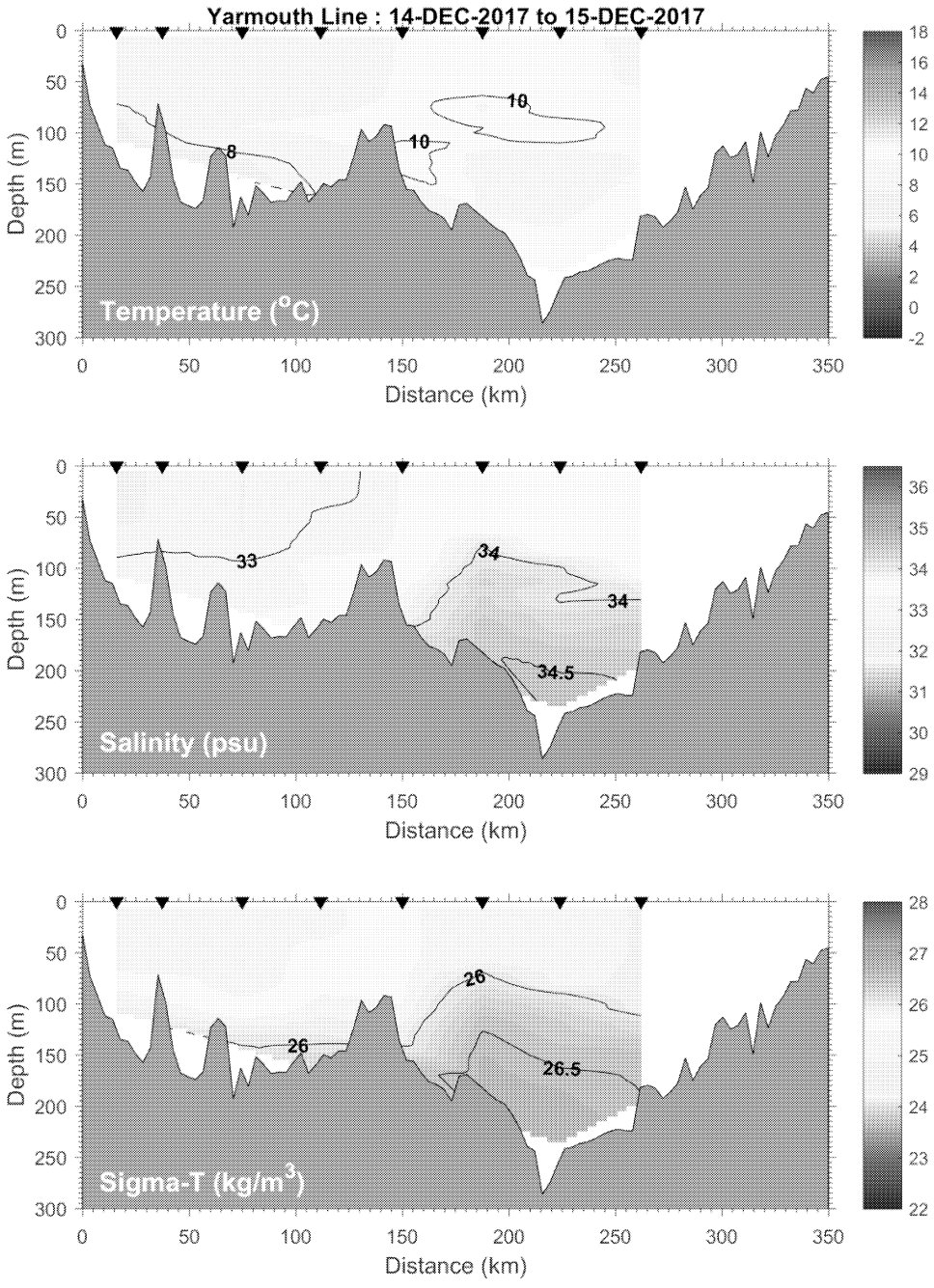
Peter Smith Line

Section



Yarmouth Line

Section

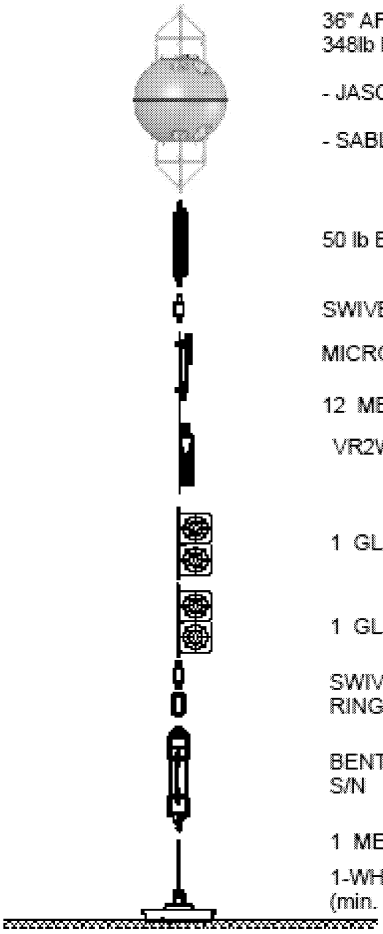


Appendix 5. Mooring Diagrams

Recoveries

MOORING # 1947
Cetacean Mooring - St. Ann's Bank
Dr. H. Moors-Murphy Sept 2016

Rev 1
2016 Mar 16
J. Barthelotte
model: 1950a4



350 METERS

36" AF AMAR BUOY, 20646-0750
348lb BUOYANCY, 750m MAX DEPTH

- JASCO AMAR S/N:

- SABLE BEACON IMEI:

50 lb BALLAST

SWIVEL

354 METERS

MICROCAT (1m below swivel) S/N:

12 METERS OF 3/16" WIRE COATED TO 1/4"

VR2W (1 m above BUB) S/N:

1 GLASS BUB PACKAGE

1 GLASS BUB PACKAGE

SWIVEL
RING

BENTHOS 866A ACOUSTIC RELEASE
S/N
KHz EN REL ID

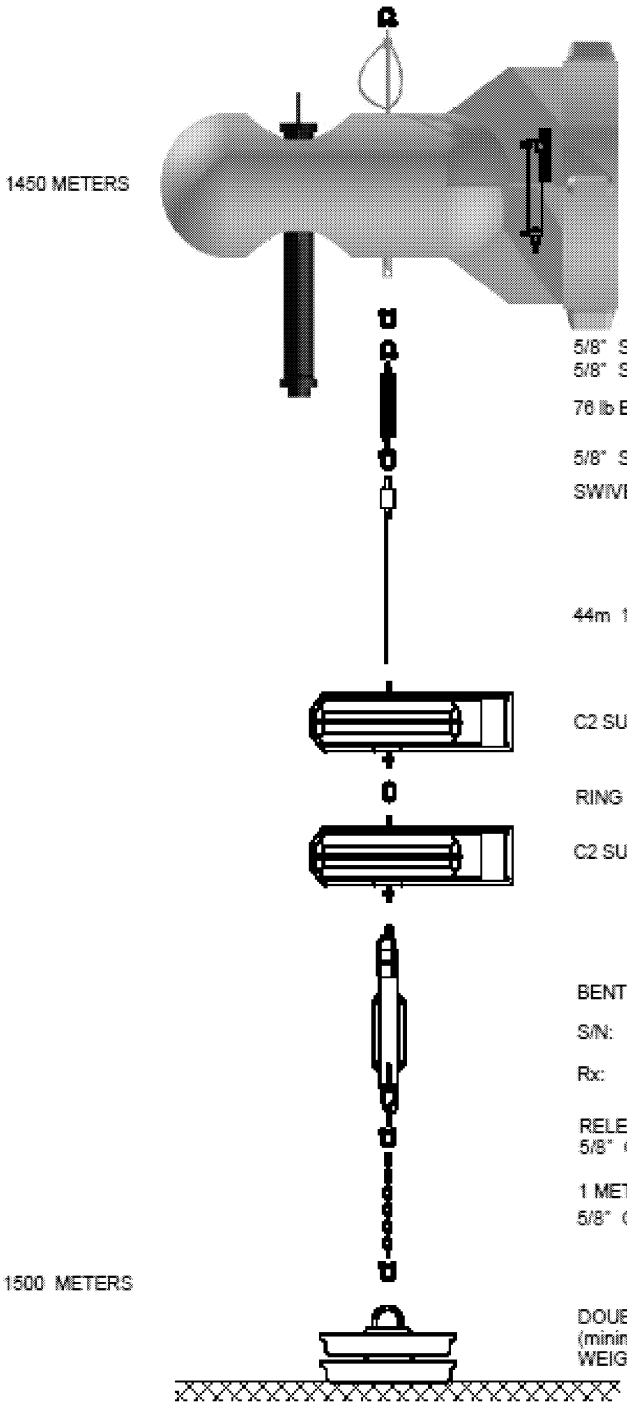
1 METER 5/8" CHAIN

1-WHEEL ANCHOR WEIGHT:
(min. 870 lb)

370 METERS

MOORING # 1948
Cetacean Mooring - The Gully
Dr. H. Moors-Murphy Sept 2016

Rev B:
Model 1948b1
2016 Mar 11
J. Barthelotte



5/8" SS SAFETY SHACKLE

SYNTACTIC FOAM BUOY
500lb BUOYANCY

- LONG RANGER ADCP S/N:

- SABLE BEACON IMEI:

- MICROCAT ODO S/N:

5/8" SS SAFETY SHACKLE
5/8" SS SAFETY SHACKLE

78 lb BALLAST

5/8" SS SAFETY SHACKLE

SWIVEL

44m 1/4" FAIRING ROPE

C2 SUBS 17" GLASS PACKAGE

RING

C2 SUBS 17" GLASS PACKAGE

BENTHOS 865-DB ACOUSTIC RELEASE

S/N:

Rx: ENABLE: RELEASE:

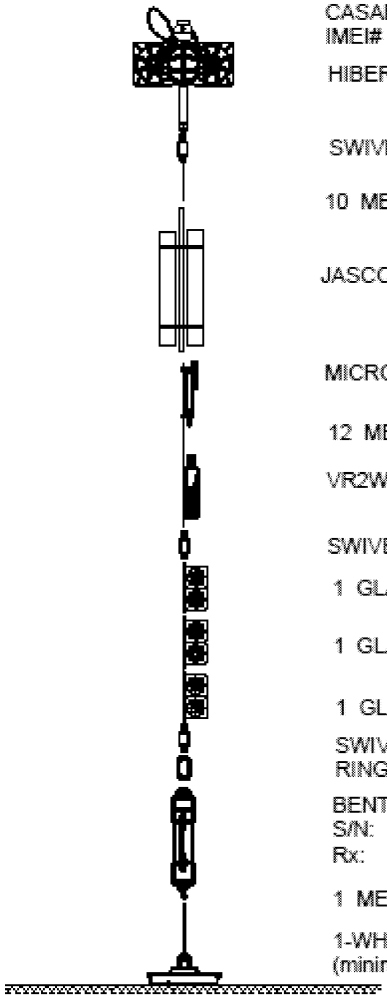
RELEASE LINK ASSEMBLY
5/8" GALVANIZED SAFETY SHACKLE

1 METER 5/8" GALVANIZED CHAIN
5/8" GALVANIZED SAFETY SHACKLE

DOUBLE WHEEL ANCHOR
(minimum 1200 lb)
WEIGHT =

MOORING # 1949
Cetacean Mooring - Emerald Basin
Dr. H. Moors-Murphy Sept 2016

Rev 1
Model 1949a1
2016 Mar 16
J. Barthelotte



173 METERS

CASABEL IRIDIUM BEACON
IMEI#

HIBERNIA PACKAGE WITH PICK-UP

SWIVEL

10 METERS OF 3/16" WIRE COATED TO 1/4"

185 METERS

JASCO AMAR S/N

MICROCAT (1 m BELOW AMAR) S/N:

188 METERS

12 METERS OF 3/16" WIRE COATED TO 1/4"

198 METERS

VR2W (1 m ABOVE SWIVEL) S/N:

SWIVEL

1 GLASS BUB PACKAGE

1 GLASS BUB PACKAGE

1 GLASS BUB PACKAGE

SWIVEL
RING

BENTHOS 866-A ACOUSTIC RELEASE
S/N:
Rx: ENABLE: RELEASE:

1 METER 5/8" CHAIN

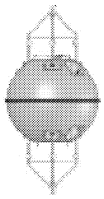
1-WHEEL ANCHOR
(minimum 820 lb) WEIGHT:

205 METERS

MOORING # 1950
Cetacean Mooring - Stone Fence
Dr. H. Moors-Murphy Nov 2016

Rev 2
2016 Nov 2
J. Barthelotte
model: 1950a4

431 METERS



36" AF AMAR BUOY, 20646 Rev 01
348lb BUOYANCY, 750m MAX DEPTH

- JASCO AMAR S/N:

- SABLE BEACON IMEI:

- MICROCAT S/N:

SWIVEL

434 METERS

MICROCAT (1 m below swivel) S/N:

12 METERS OF 3/16" WIRE COATED TO 1/4"

VR2W (1 m above BUB) S/N:

1 GLASS BUB PACKAGE

1 GLASS BUB PACKAGE

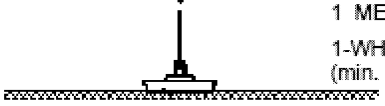
SWIVEL
RING

BENTHOS 866A ACOUSTIC RELEASE
S/N
KHz EN REL ID

1 METER 5/8" CHAIN

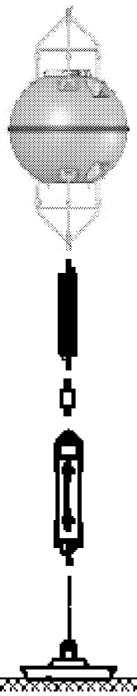
1-WHEEL ANCHOR WEIGHT:
(min. 870 lb)

450 METERS



MOORING # 1996 NSCMP Sept 2016
Dr. Dave Hebert

Rev A1
2016 June 9
J. Barthelotte
model: 1950a4



165 METERS

36" AF BUOY
348lb BUOYANCY
750m MAX DEPTH

- 150kHz ADCP S/N:
- MICROCAT S/N:
- BEACON IMEI:

50 lb BALLAST

SWIVEL
BENTHOS 866A
ACOUSTIC RELEASE
S/N
KHz EN REL ID

1 METER 5/8" CHAIN

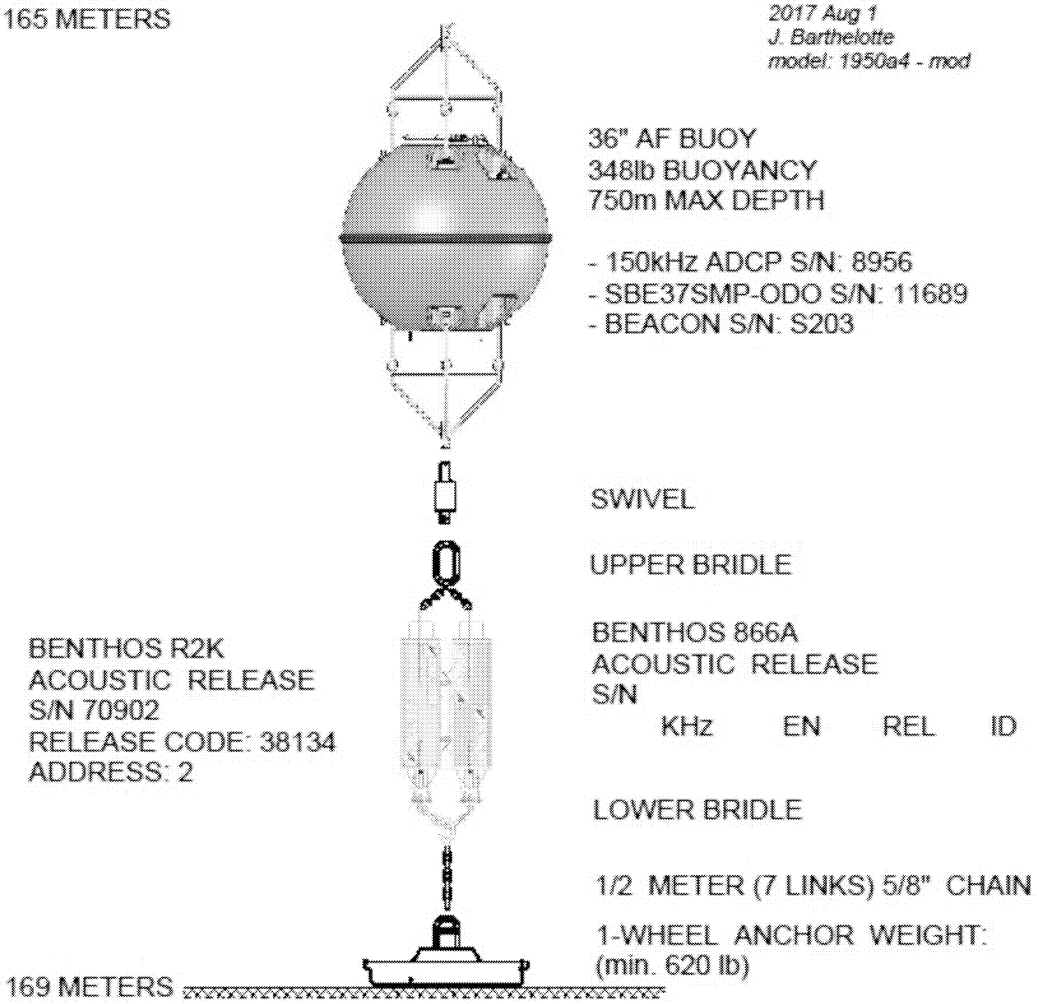
1-WHEEL ANCHOR WEIGHT:
(min. 600 lb)

169 METERS

Deployments

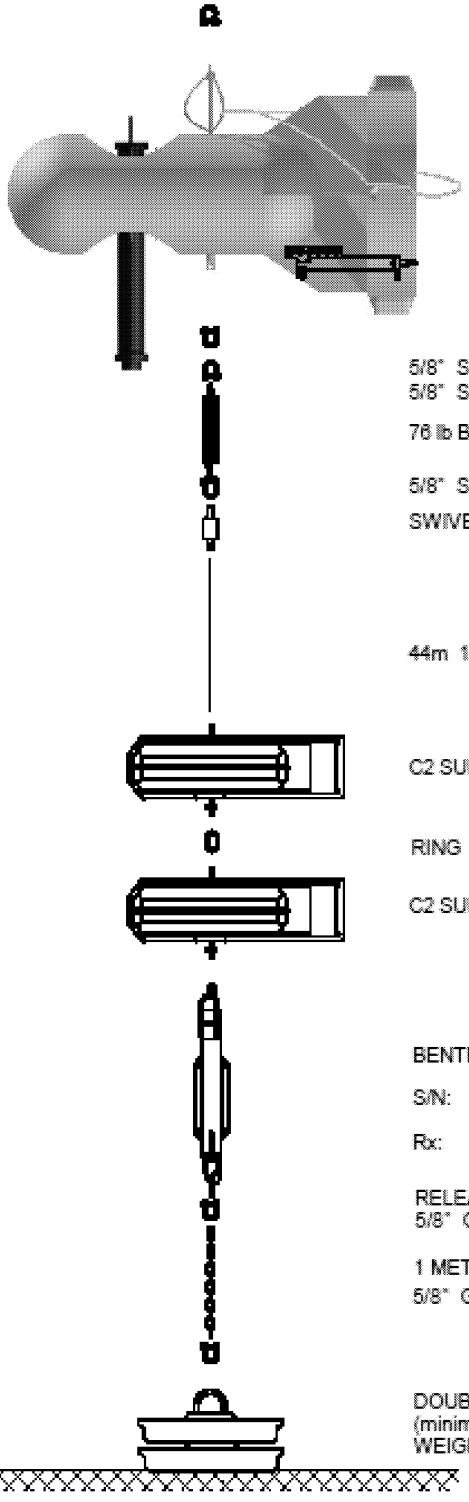
MOORING # 2024 NSCMP Oct 2017
Dr. Dave Hebert

Rev B1
2017 Aug 1
J. Barthelotte
model: 1950a4 - mod



MOORING # 2025
Cetacean Mooring - The Gully
Dr. H. Moors-Murphy Oct 2017

Rev A2:
Model 1948b1
2017 July 13
J. Barthelotte



1450 METERS

5/8" SS SAFETY SHACKLE

SYNTACTIC FOAM BUOY
580lb BUOYANCY
1500 m depth max

- JASCO AMAR S/N:

- SABLE BEACON IMEI:

- MICROCAT ODO S/N:

5/8" SS SAFETY SHACKLE
5/8" SS SAFETY SHACKLE

76 lb BALLAST

5/8" SS SAFETY SHACKLE

SWIVEL

44m 1/4" FAIRING ROPE

C2 SUBS 17" GLASS PACKAGE

RING

C2 SUBS 17" GLASS PACKAGE

BENTHOS 865-DB ACOUSTIC RELEASE

S/N:

Rx: ENABLE: RELEASE:

RELEASE LINK ASSEMBLY
5/8" GALVANIZED SAFETY SHACKLE

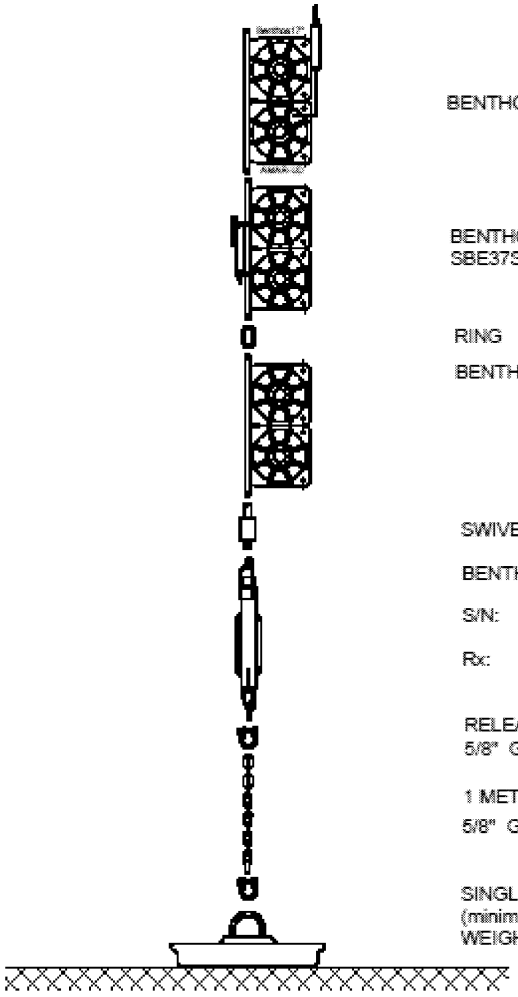
1 METER 5/8" GALVANIZED CHAIN
5/8" GALVANIZED SAFETY SHACKLE

1500 METERS

DOUBLE WHEEL ANCHOR
(minimum 1200 lb)
WEIGHT =

MOORING # 2026
Cetacean Mooring - The Gully - Deep
Dr. H. Moors-Murphy Oct 2017

Rev A3:
Model 2026opta
2017 July 28
J. Barthelotte



3494 METERS

BENTHOS 17" GLASS SPHERE + AMAR-UD

3496 METERS

BENTHOS 17" GLASS BUB PACKAGE
SBE37SM MICROCAT S/N

RING

BENTHOS 17" GLASS BUB PACKAGE

SWIVEL

BENTHOS 865-A ACOUSTIC RELEASE

S/N:

Rx: ENABLE: RELEASE:

RELEASE LINK ASSEMBLY
5/8" GALVANIZED SAFETY SHACKLE

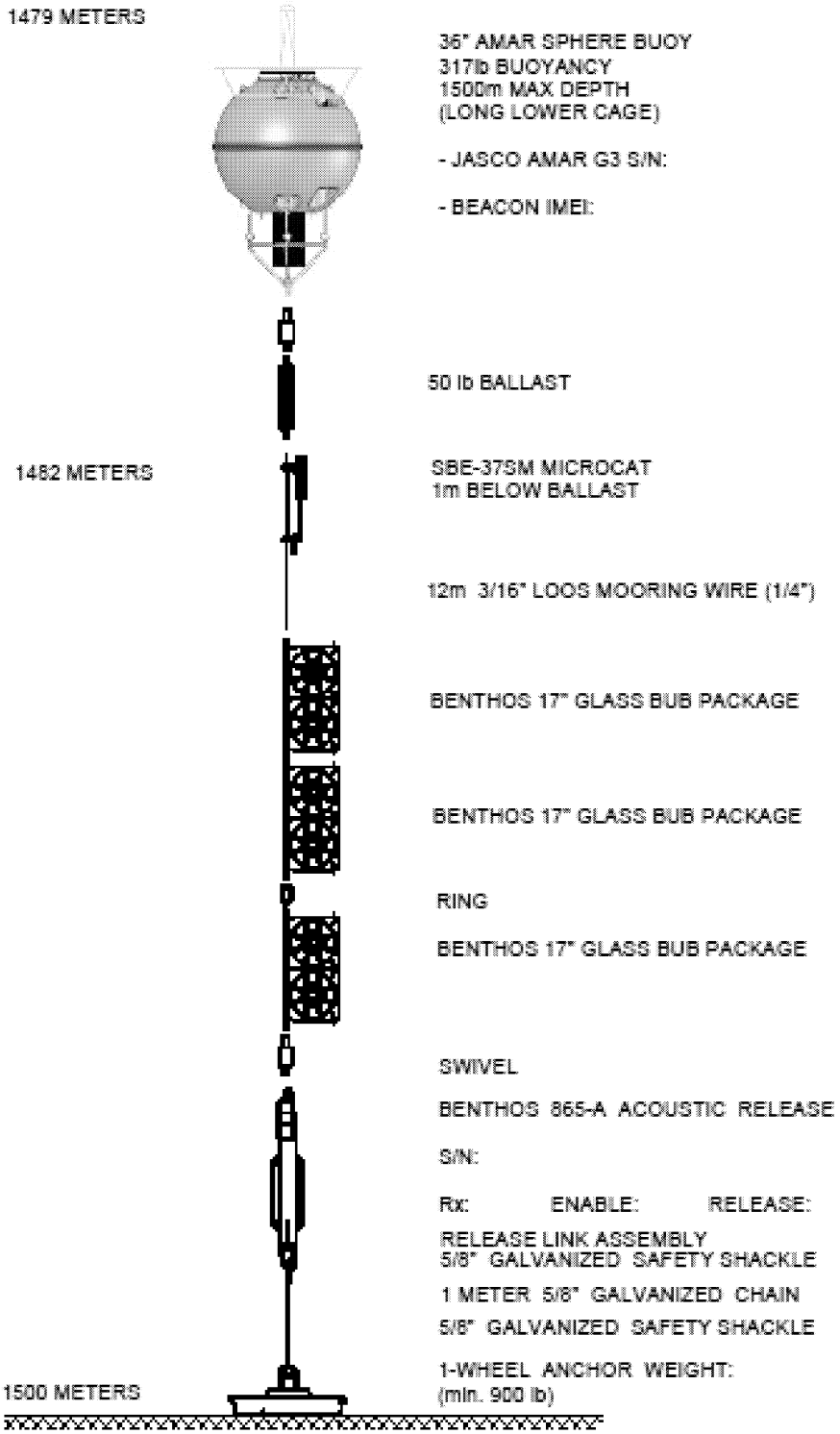
1 METER 5/8" GALVANIZED CHAIN
5/8" GALVANIZED SAFETY SHACKLE

SINGLE WHEEL ANCHOR
(minimum 600 lb)
WEIGHT =

3500 METERS

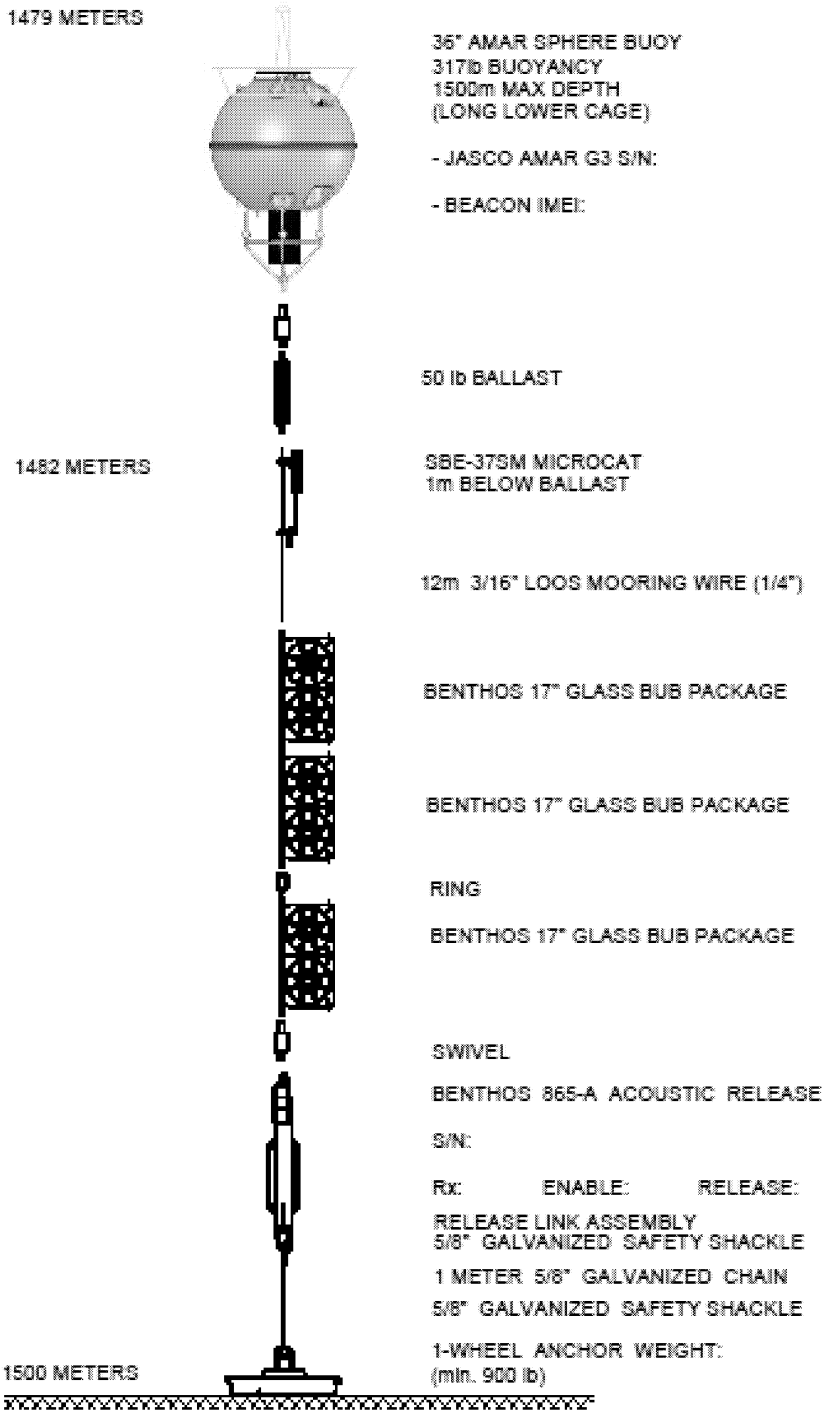
MOORING # 2027 Cetacean - Dawson Canyon Oct 2017
Dr. Hilary Moors-Murphy

Rev A2
2017 July 13
J. Barthelotte
model: 2027a2



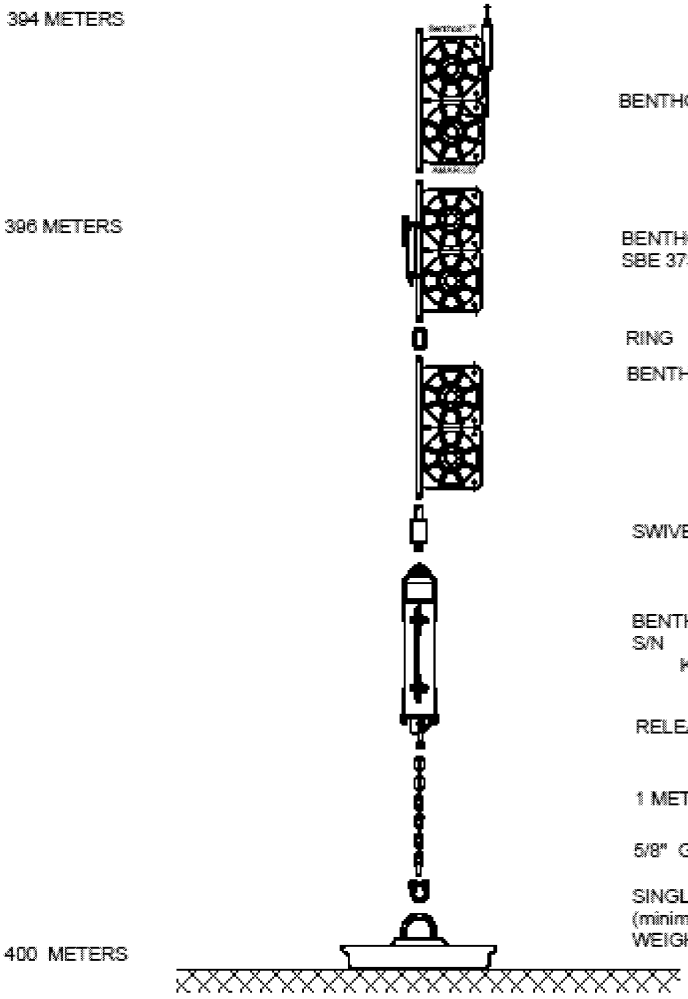
MOORING # 2028 Cetacean - Logan Canyon Oct 2017
Dr. Hilary Moors-Murphy

Rev A2
2017 July 13
J. Barthelotte
model: 2027a2



MOORING # 2029
Cetacean Mooring - St. Ann's Bank
Dr. H. Moors-Murphy Oct 2017

Rev A3:
Model 2026opta
2017 July 28
J. Barthelotte



Appendix 6. Endeavor TSG Configuration File – 27Nov2017a.xmlcon

Date: 01/29/2018

Instrument configuration file: R:\Science\BIODataSvc\SRC\2010s\2017\EN606\Ship Deliverables\EN606_Hebert\tsg\raw\27Nov2017a.XMLCON

Configuration report for SBE 21 Seacat Thermosalinograph

Remote temperature : SBE 3
External voltage channels : 2
Sample interval : 6 seconds
NMEA position data added : Yes
NMEA depth data added : No
NMEA time added : No
NMEA device connected to : deck unit
Scan time added : No

1) Frequency 0, Temperature

Serial number : 1578
Calibrated on : 14-Dec-16
G : 4.19581328e-003
H : 5.93731371e-004
I : 3.79065958e-006
J : -1.86524830e-006
F0 : 1000.000
Slope : 1.00000000
Offset : 0.0000

2) Frequency 1, Conductivity

Serial number : 1578
Calibrated on : 14-Dec-16
G : -4.01390242e+000
H : 4.78841495e-001
I : 1.20442267e-003
J : -2.89460350e-005
CTcor : 3.2500e-006
CPcor : -9.57000000e-008
Slope : 1.00000000
Offset : 0.00000

3) Frequency 2, Temperature, 2

Serial number : 0604
Calibrated on : 15-Dec-16

G : 4.80105098e-003
H : 7.12509078e-004
I : 4.85485321e-005
J : 6.14112724e-006
F0 : 1000.000
Slope : 1.00000000
Offset : 0.0000

4) A/D voltage 0, Fluorometer, WET Labs WETstar

Serial number : 1177
Calibrated on : 17-Mar-2017
Blank output : 0.063
Scale factor : 6.100

5) A/D voltage 1, Fluorometer, WET Labs ECO-AFL/FL

Serial number : 478
Calibrated on : 12142016
Dark output : 0.0170
Scale factor : 2.40000000e+001

Scan length : 34

Appendix 7. Data and Meta-data Collections

The mission data is uniquely organized because the charter vessel provided us with data files upon our departure for all shipboard instrumentation. The raw CTD data was processed using the Endeavor's protocols but was also processed using CTD-Dap to meet AZMP Maritimes standards.

The mission data and metadata is held here:

R:\Science\BIODataSvc\SRC\2010s\2017\EN606

This folder includes:

1. Raw and processed CTD data, configuration files and plots
2. Lists of stations and Navigation
3. Logs as they are scanned
4. Raw shipboard analysis (Winkler, Autosal, Turner Fluorometer)
5. Operation metadata (Elog)
6. The AZMP database template for the mission and summary reports
7. Ship deliverables
    a. ADCP
    b. CTD raw data and Endeavor processing
    c. Navigation
    d. SCS log
    e. TSG data and configuration files
    f. Winch logs
8. The BioChem folder will contain land based laboratory analysis as it becomes available, and includes:
    a. HPLC/Absorption
    b. POC/PON
    c. Nutrients
    d. Zooplankton
    e. Flow cytometry (samples collected but may be late to process)
    f. PCO2
    g. TIC/TA

CRUISE REPORT

HUDSON 2018004

SCOTIAN SHELF

AZMP TRANSECTS +

April 6 - 24

Table of Contents

CRUISE NARRATIVE

Highlights

Area Designation:	NAFO Regions: 5Ze, 5Y, 4X, 4W, 4Vs, 4Vn, 3Pn, 3Ps Extent: 41° 46'N - 47° 35'N; 056° 02'W - 070° 16'W
Expedition Designation:	HUD2018004 or 18HU18004 (ISDM format)
Chief Scientist:	Andrew Cogswell Ocean Ecosystem Science Division Marine Ecosystem Section Department of Fisheries and Oceans Bedford Institute of Oceanography PO Box 1006 Dartmouth, NS, Canada B2Y 4A2 Andrew.Cogswell@dfo-mpo.gc.ca
Ship:	CCGS Hudson (call sign - CGDG) oceanographic research vessel
Ports of Call:	April 6th, 2018 – Depart BIO, Dartmouth, NS Apr 19th, 2018 – Emergency ship repair, Sydney, NS Apr 20th, 2018 – Depart, Sydney, NS Apr 24th, 2018 – Arrive Mulgrave, Dartmouth, NS
Cruise Dates:	Apr 6th – 24th

Mission Summary

Overview

One day prior to departure on April 5th, while conducting a pull test on the CTD winch, we realized the joy stick controls were malfunctioning. When the winch was set to the prescribed low speed required for producing enough torque to recover and deploy the CTD, the winch payed out regardless of the joy stick position. All testing on the winch to that point had been conducted in high speed and was functioning normally. Pennicon was called to service the winch and they worked with Hawboldt to diagnose the issue. Just after 1800 on the 5th, the issue had been resolved and a re-termination of the CTD cable was completed by 2300 that evening. A special thanks to the ship's crew, Pennicon, Hawboldt, DFO Field Ops and Terry Cormier and Dave Levy for their extra effort to get the winch functioning properly the night before sailing.

Just after departure from the BIO Jetty at ~9 am on April 6th, the CCGS Hudson conducted a compass swing, boat and fire drills and testing of the starboard life boat prior to science operations beginning in the basin at ~1300. The underway system in the forward lab was started just after pulling away from the dock. The basin tests consisted of 3 CTD deployments to diagnose an issue with the altimeter and the altimeter cable. As well, the hydro winch was tested to make sure it was functioning properly. The ship began steaming towards BBL_01 at ~1600, but off Chebucto Head the shaft temperature was increasing and an oil change was required that resulted in a short ~1-2 hour delay before we could begin steaming again. We arrived at BBL_01 at ~0100 on April 8th to begin station occupations. At ~1830 on the 9th, we completed the BBL and PS lines and began the Plymouth Line at PL_09. At ~1200 on the 9th, the ship received word from Global Affairs Canada that the US State Department had provided our clearance to conduct work in US waters. Early in the morning of the 10th we began occupying stations along the PL line, crossing into US waters at ~1000 on April 10th. The ship continued down the PL line, but there was concern from the bridge that an evening arrival at the nearshore YL_10 station could make it difficult to navigate around fishing gear in the area. Upon completion of PL_04, the Captain suggested we occopy stations YL_06 and YL_07 during the night and early morning of April 11th and wait for day break to return to PL_03. We completed the PL line at ~1020 on the 11th and began occupying the Yarmouth Line (YL_10) at ~1200 on April the 11th. The ship worked its way down the line, crossing back into Canadian waters at ~0230 on the 12th, and finishing the line ~8 hours later before proceeding to HL_01.

Occupation of the Halifax Line stations began at ~0100 on April 13th. A station occupation was added to the plan at HL_02.25 in close proximity (~2 km) to a DFO glider that was in the area. Upon completion, operations proceeded as normal until ~ 1800 on April 14th when the CTD deck unit threw an error during the bottom of the cast at HL_07 in ~2800 m of water. This led to a string of diagnostics and 7 coinciding CTD test deployments that finally culminated in a successful full profile at ~1030 on April 15th. The resulting ~17 hrs of lost time meant that HL_12, 13 and 14 were cut from the mission plan. Approximately 24 hours later on April 16th at 1000, the Halifax Line was finished at HL_11 and the Hudson departed for the Gully MPA. The finer details associated with the CTD repairs, and all other aspects of the CTD operations throughout the mission, are discussed at length in the CTD summary of this report.

The Hudson arrived in the Gully at station SG_28 at ~2200 on the 16th, followed by typical ring net and CTD occupations at GULD_03 and GULD_04 overnight and early morning of the 17th. At SG_23 the ring net was deployed, but the continued to deteriorate during deployment. The forecast suggested that the winds and associated sea state would be beyond safe working conditions for at least the next 12 hours, so the CTD at this location was cancelled and a course was set for station 9 on the South Eastern St. Pierre Bank Line (SESPBL - A line added to the plan to satisfy the core requirements of the NL AZMP program that could not occupy the line due to weather). During the early part of the transit to this location under heavy seas, the Senior Engineer's Cabin experienced flooding, due to a leaky starboard scupper that could not be accessed under a container. The decision was made to halt the transit and begin the steam back in to Sydney to make the necessary repairs. On the way back to Sydney, the Louisbourg Line was occupied starting at LL_07 at ~2000 on April 17th. LL_08 and LL_09 were dropped because of the sea state and wind direction (more on this later). The goal was to have the ship alongside in Sydney on the morning of April 19th. We were able to occupy LL_07 to LL_01 and STAB_01 to STAB_04 before heading for Sydney at ~2200 on April 18th.

We arrived at the dock in Sydney on the morning of the 19th at ~0830. The underway system was shut off upon docking and the container was removed from the ship by ~0930. We were instructed by the Captain to await an update later in the day about the state of the repairs and a possible departure time. By mid-afternoon on the 19th, we received notice that the repairs were complete, the container would go back on board that evening and the ship would set sail at ~0800 on the 20th, bound for CSL_01. A cruise track was provided to the bridge based on the amount of remaining time and the likely speed of the vessel given the long range wind forecast. Prior to leaving the Harbour, the underway system was turned back on.

Station occupations began at CSL_01 at ~1400 on April 20th, and finished ~15 hours later at 0500 on the 21st before proceeding to STAB_05. STAB_06 was dropped from the itinerary because it is not within the bounds of the MPA and was only recently added to the AZMP sampling suite. After completing the occupation of STAB_05 at 1330 on April 21st, the Hudson began the long steam towards LL_08, arriving at ~0330 on the 22nd. Work at LL_08 and LL_09 was completed at ~1300 on April 22nd before steaming for BP_00 on the eastern shelf at the mouth of the Laurentian Channel. Work began at ~2200 on April 22nd at BP_00 and continued through the night and morning of the 23rd, finishing at BANQ_B1 at ~1300 before setting sail for the crew change in Mulgrave. Just after departure from Sydney on the 20th, we were informed that the berth would not be available for the Hudson, so an alternate port was chosen for the exchange. We arrived at the Mulgrave dock early in the morning of the 24th.

Over the 18 day mission, the CCGS Hudson logged ~2461 nm and AZMP science staff conducted 180 separate operations at 85 stations (Figure 1). Table 1 breaks down the operations by sampling gear for each leg of the trip. The table also points to figures that display the deployment locations for each gear type. Each of these figures is accompanied by a table of coordinates detailing each deployment of that gear type. Table 2 contains the break down in time allocated to each gear type.

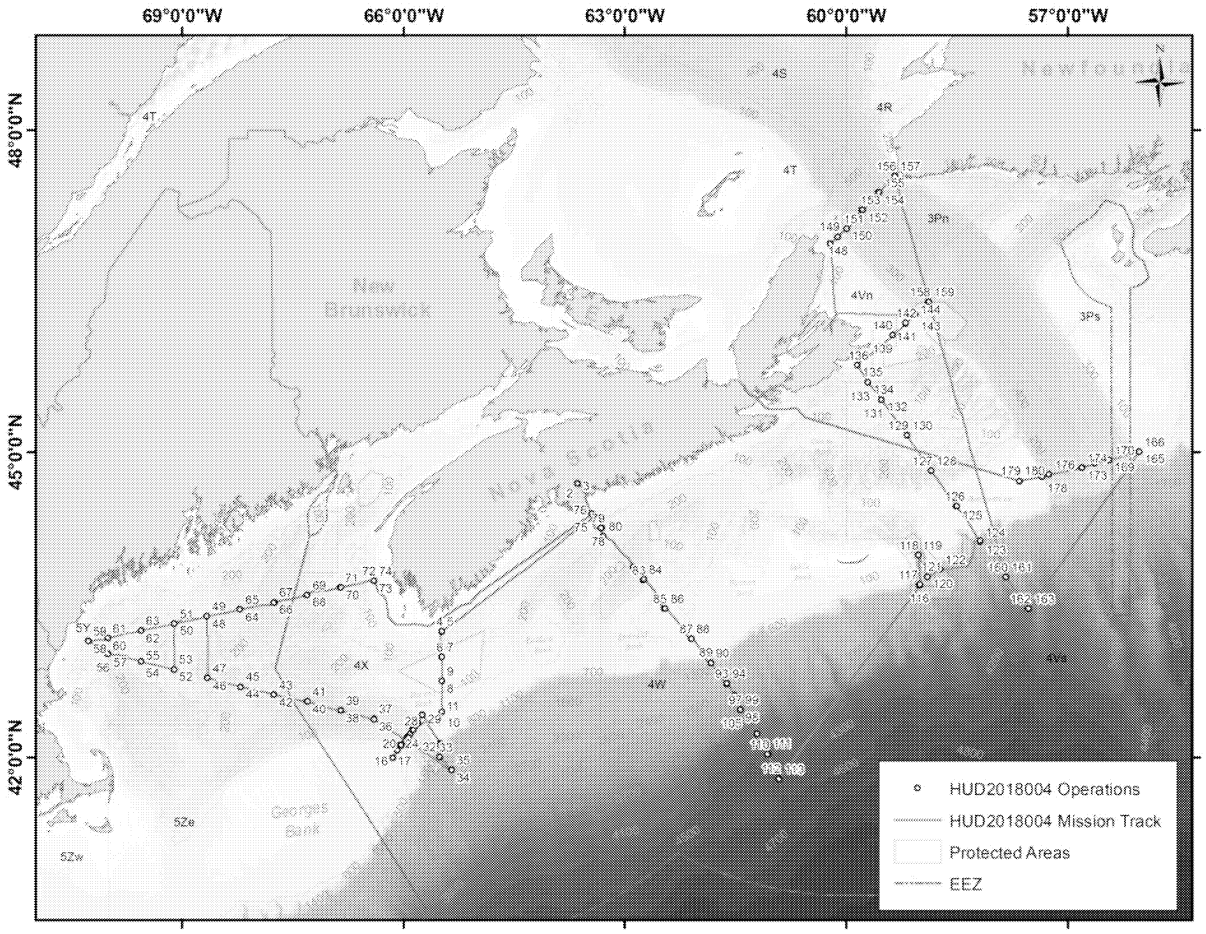


Figure 1. The locations for all 180 events during the HUD2018004 AZMP spring survey. Some overlapping event labels may not visible.

Table 1. Summary of operations during the HUD2018004 AZMP spring survey.

Operation	# of Operations	Figure
CTD	95	4
Vertical Ring Net Tows	85	29

Table 2. Break down of operational time by gear type during HUD2018004.

Gear	~Operation Duration (hrs)
CTD	~66
Vertical Net Tows	~27

Mission Participants

A complete crew list for this mission can be found in Appendix 2. Please refer to Table 3 for a list of Science Staff who participated during HUD2018004.

Table 3. List of science staff aboard the HUD2018004 fall AZMP mission.

	Name	Affiliation	Duty	Shift
1	Benjamin, Robert	DFO – PCSD	Data Manager	Day
2	Cogswell, Andrew **	DFO – OESD	Chief Scientist	Day
3	Cormier, Terry	DFO – OESD	CTD Technician	Night
4	Waclawik, Magda	Dal – Bertrand/LaRoche	Technician	Split
5	[redacted]	Dal – Bertrand/LaRoche	Technician	Split
6	Wilson, Colleen	Dal – Hays	CTD Operator/Elog	Day
7	Layton, Chantelle	DFO – OESD	CTD Operator/Elog	Night
8	Levy, Dave	DFO – OESD	CTD Technician	Night
9	MacIsaac, Kevin	DFO – OESD	CTD/Nets/Biologist	Night
10	Perry, Tim	DFO – OESD	Lab Technician	Night
11	Spry, Jeffrey	DFO – OESD	CTD/Nets/Biologist	Day
12	Thamer, Peter	DFO – OESD	Lab Technician	Day
13	Winkel, Jeannine	ECCC – CWS	Bird/Mammal	Day

**Chief Scientist
DFO: Department of Fisheries and Oceans Canada
OESD: Maritimes - Ocean Ecosystem Science Division
PCSD: Maritimes - Program Coordination and Support Division
EC-CWS: Environment Canada - Canadian Wildlife Service
DAL: Dalhousie University

Objectives

There were 12 defined objectives in the final version of the Form B submitted to Coast Guard Headquarters on Aprilt 4th, 2018 (below). Of these, 2 objectives were cancelled prior to sailing (5 and 12). It was decided that the AZOMP mission would deploy the ARGO floats intended for the AZMP mission and a small vessel (Sigma T) was used to deploy the ALSEAMAR glider. Table 4 describes whether each of these objectives was met along with any relevant supporting commentary.

Primary

1. Obtain observations of the hydrography and distribution of nutrients, phytoplankton and zooplankton at standard sampling stations along "**core**" Atlantic Zone Monitoring Program sections within the Maritimes Region (**Contact Mr. Andrew Cogswell** - http://www.bio.gc.ca/science/monitoring-monitorage/azmp-pmza-eng.php.).

Additional

2. Occupy stations in support of the extended Halifax Line (XHL) (HL_08 and greater) (**Contact Dr. Igor Yashayaev).**
3. Carry out hydrographic, chemical and biological sampling in support of Gully MPA monitoring initiatives by Oceans and Coastal Management Division (**Contact Dr. Dave Hebert -** http://inter-w02.dfo-mpo.gc.ca/Maritimes/Oceans/OCMD/Gully/Gully-MPA).
4. Nutrients and hydrography across the Northeast Channel and Gulf of Maine as part of NERACOOS Cooperative Agreement, (**Contact Dr. Dave Hebert** - http://www.neracoos.org/).

5. Deploy 3 ARGO floats in support of the International Argo Float Program (**Contact Dr. Blair Greenan** - http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/argo/index-eng.html).
6. Collect underway and CTD water samples at specified locations and depths to fulfil the regional component of an Aquatic Climate Change Adaptation Services Program (ACCASP) initiative investigating the delineation of ocean acidification and calcium carbonate saturation state of the Atlantic zone (**Contact Dr. Kumiko Azetsu-Scott** - http://www.dfo-mpo.gc.ca/science/oceanography-oceanographie/accasp-psaccma/index-eng.html).
7. Collect water samples for the Bertrand lab at Dalhousie University to evaluate whether and how organic and organometallic micronutrients influence primary productivity and phytoplankton community structure on the Scotian Shelf (**Contact Erin Bertrand** – Erin.Bertrand@dal.ca).
8. Collect water samples from strategic locations and depths to support a microbial community analysis via DNA, RNA and flow cytometry, as well as the isolation of novel diazotrophs (**Contact Dr. Julie Laroche** - http://www.dal.ca/faculty/science/biology/faculty-staff/our-faculty/julie-laroche.html).
9. Bird and mammal observations as part of EC-CWS sea-bird observation program and in fulfilment of Gully and St. Anns Bank MPA occupation requirements (**Contact Carina Gjerdrum –** carina.gjerdrum@canada.ca).
10. Carry out hydrographic, chemical and biological sampling at stations in the St. Anns Bank MPA as continued support for the Oceans and Coastal Management Division monitoring strategy (**Contact Dr. Dave Hebert -** http://www.dfo-mpo.gc.ca/oceans/mpa-zpm/stanns-sainteanne-eng.html).
11. Conduct hydrographic, chemical and biological sampling across the mouth of the Laurentian Channel and St. Pierre Bank. This transects have been implemented to enhance our understanding of hydrographic phenomenon in these areas in support of current modelling efforts (**Contact Dr. Dave Brickman**).
12. Possibly deploy an ALSEAMAR glider in support of the DFO glider group (**Contact Dr. Clark Richards**).

Table 4. Status of objectives upon completion of the HUD2018004 mission.

Objective	Status	Comments
1	Completed	All core stations were fully occupied but there was a 4 day delay between the occupation of LL_07 and LL_08 due to emergency ship repairs.
2	Partially Completed	Stations HL_12 to 14 were cancelled because of delays caused by CTD issues at HL_07 on April 14th and 15th.
3	Mostly Completed	With the exception of a single CTD at SG_23 on April 17th that was cancelled due to sea-state conditions, Gully operations were a success.
4	Completed	All PS, YL and PL stations were completed as planned.
5	Cancelled	Cancelled prior to sailing.
6	Completed	Samples acquired at all stations identified prior to sailing.
7	Completed	
8	Completed	
9	Completed	
10	Mostly Complete	STAB stations 1-4 were occupied on April 18th before returning to Sydney for vessel repairs. STAB_06 was cancelled, and STAB_05 was occupied 3 days later on the 21st.
11	Mostly Completed	Due to time constraints at the end of the mission, BANQ_B5 and BANQ_B2 were cancelled, but BP_00 was added to the eastern bank of the Laurentian Channel Line.
12	Cancelled	The glider was deployed by the Sigma T during the HUD2018004 mission.

SUMMARY OF ACTIVITIES

CTD Summary

Narrative

As summarized in Table 1, there were a total of 95 CTD casts during the mission (Figure 4 and Table 6). Ten of these were aborted casts, which included: events 073 (YL_01), 098-104 (HL_7), 116 (SG_28), and 148 (CSL_02).

Starting at event 001 in the Basin (HL_00), the Valeport Altimeter (#59017) was replaced with a Benthos altimeter (#49559) because the Valeport was not providing an accurate bottom distance (off by ~50 m). A second test CTD cast in the Basin (event 002) threw a deck unit error, the cast was aborted and it was determined that the new cable for the recently swapped Benthos altimeter was the problem. From event 002 to event 035 the configuration file HUD2018004C was used (Table 5). Prior to event 037 at PL_09, the SeaPoint CDOM UV Fluorometer was removed. The data produced by this sensor has been jumping from what seems to be a reasonable value, to 0 and back again during a single cast. The problem was observed as early as the spring 2017 mission but the sensor had not been sent back for repair and there is no spare (**a spare UV fluorometer should be purchased in 2018 if possible**). The configuration file HUD2018004D.xmlcon was used between events 037 and 113 (HL_11) (Table 5).

During event 073 (YL_01) the primary T/S/O sensors were returning unreasonable data values and the cast was aborted. Upon recovery, the primary plumbing was flushed with Triton and the pressure relief valve was replaced before the CTD was re-deployed at the same station for event 074. The primary data continued to be incorrect upon descent, but upon ascent the blockage was removed and data values for the primary and secondary systems were in better agreement. For event 074 at YL_01 the secondary sensor values were entered into the AZMP template rather than the incorrect primary values.

During event 098 at HL_07 at ~2784 m on the upcast, the deck unit threw an error and an RS-232 Communications Timeout. Prior to the redeployment at HL_07 during event 099, all sensors with the exception of the primary and secondary T/S/O and the Y (JT2) for the altimeter and the PAR were removed. The deck unit threw the same error at ~2700 m of the upcast and the CTD was aborted. The secondary sensors and the Y to the altimeter and PAR were dummied prior to the next cast (event 100) so only the primary T/S/O sensors were connected to the 9+. This cast was successful, so the problem was narrowed down to the either one of the secondary sensors (T/S/O) or one of the sensors on the Y. When the secondary sensors were added on during event 101, the CTD was also successful so the problem had something to do with the Y. Prior to event 102, the Y was reattached to the 9+ with a new altimeter but the deck unit threw an error around 550 m on descent, so the altimeter was not the problem. Now the issue had been narrowed down to the cables in the Y or the PAR sensor. Before the next cast (event 103) the Y cable had been replaced, but this cast also failed at 608 m on descent and was aborted. Finally, before event 104, the altimeter cable leading to the Y was replaced. This failed as well upon descent, so prior to the next cast (event 105) the PAR was dummied off and the cast was successful. The trouble shooting at HL_07 took ~14 hours, leading to the cancellation of stations HL_12 – 14. **Ultimately, the PAR sensor had failed and we did not have a spare so it was left dummied off for the remainder of the mission.**

During the deep casts on the XHL, a periodic signal oscillation was noticed in the primary oxygen sensor that increased in amplitude as the casts grew deeper. As a result, after event 113 (HL_11) the primary oxygen sensor (#0133) was replaced with #3030 for the remainder of the mission. From events 116 (SG_28) to event 159 (STAB_05) the configuration file HUD2018004e.xmlcon was used (Table 5). During event 116 the deck unit threw and error that was likely caused by a faulty PAR unit, which was removed from the CTD for the rest of the mission. **We will need to service this PAR sensor and purchase another in 2018 as a spare.** During event 121 (GULD_04), the primary oxygen sensor oscillations were observed again, so some caution should be used in interpreting deep water primary oxygen throughout the mission. At this point, the Y cable for the oxygen sensor and the primary oxygen had been replaced. After event 159 (STAB_05) on the long steam south to LL_08, the SBE 9 unit (#1214) was replaced with unit #0370. The problem had been resolved during events 161 and 163 (LL_08 and LL_09) and configuration file HUD2018004f.xmlcon was used from event 161 to the end of the mission (event 180 at BANQ_B1) (Table 5).

Throughout the mission, 8 bottles on the CTD did not fire. As a result, as standard practice for both shifts after each cast, the CTD firing mechanism is now washed with Triton solution and rinsed with fresh water.

Table 5. Configuration files used throughout the mission.

Configuration File	Event Range	Problem	Appendix
HUD2018004b	001	Altimeter change	1a
HUD2018004c	002 - 035	SeaPoint UV removed	1b
HUD2018004d	037 - 113	Primary oxygen replaced	1c
HUD2018004e	116 - 159	SBE 9 change	1d
HUD2018004f	161 – 180		1e

Conditions

Preliminary section plots and anomalies (where available) of temperature (°C), salinity (P.S.U.) and sigma-t (kg/m^3) in order of occupation (Browns Bank, Peter Smith, Portsmouth, Yarmouth, Halifax, Louisbourg, St. Anns Bank, Cabot Strait, and the mouth of the Laurentian Channel), can be viewed in Appendix 3.

Water temperatures observed along the shelf break were much warmer than normal (Figure 2). In fact, water temperatures were in excess of 8 degrees warmer than normal at both BBL_07 and HL_07 (Appendix 3) and surface temperatures (~14 degrees) and salinities (~35.5 P.S.U.) were well mixed from the surface to approximately 200 m (Figure 3). While this is not entirely unprecedented, it is certainly rare within the 20 year time frame of the AZMP program. The conditions were unusual enough to incite some interest from news media who picked up the story during the cruise. This is the first time that temperature, salinity and density section plots had been created and disseminated during a mission and it is something that we will continue to do in the future. A special thanks to Roger Pettipas who created all of the plots and Dave Hebert who did the interviews with various news outlets:

http://nationalpost.com/pmn/news-pmn/canada-news-pmn/researchers-find-abnormally-warm-atlantic-waters-off-nova-scotia

https://www.pressherald.com/2018/04/24/deep-current-of-unusually-warm-water-flowing-into-gulf-of-maine/

Discussions were undertaken post-cruise to determine the significance of these findings and whether further in-depth analyses are warranted.

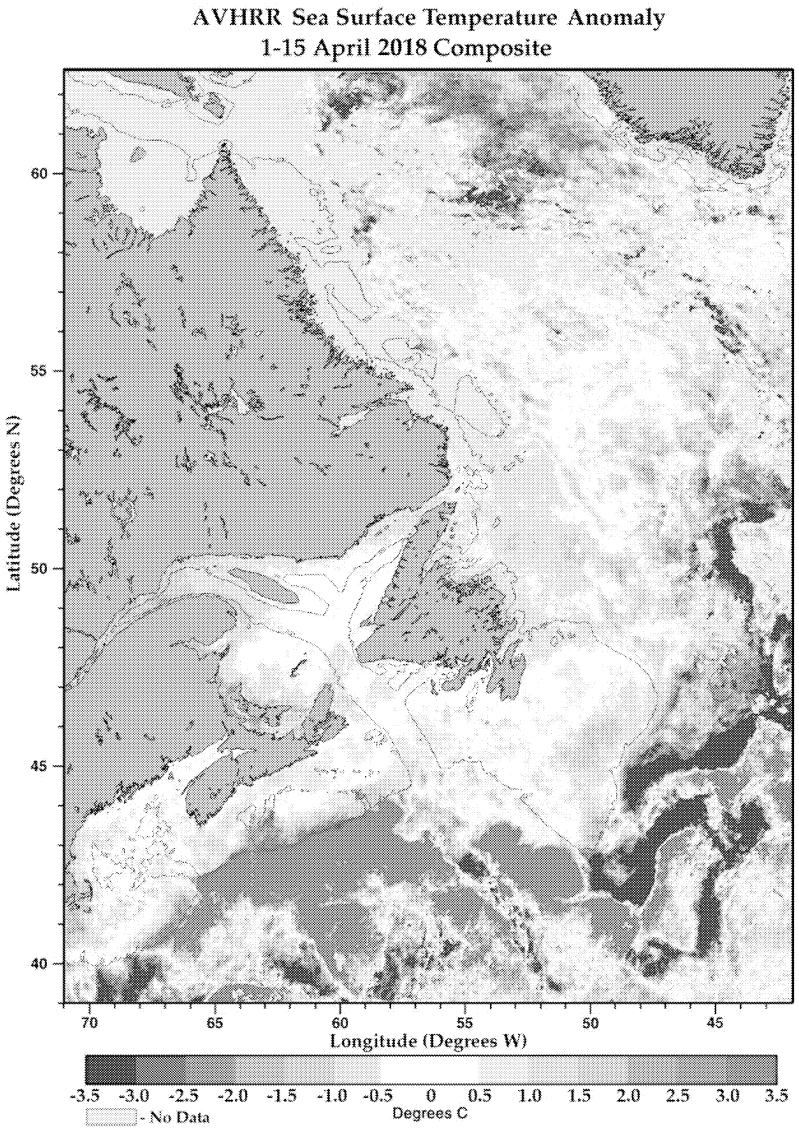


Figure 2. Sea surface temperatures along the shelf break were much warmer than the 1981 – 2010 climatology.

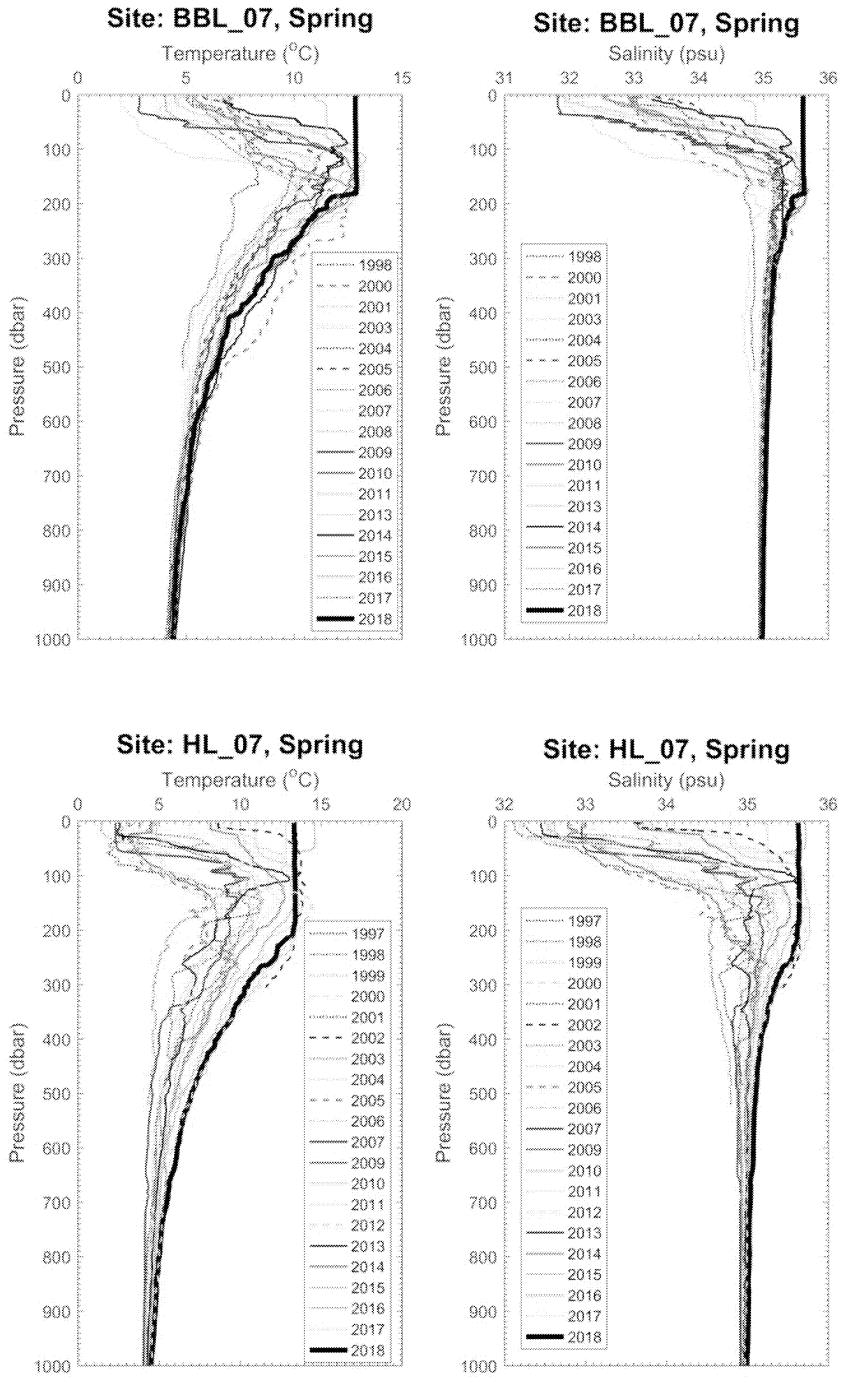


Figure 3. The temperature and salinity during the spring survey at BBL_07 and HL_07 from 1997 to 2018.

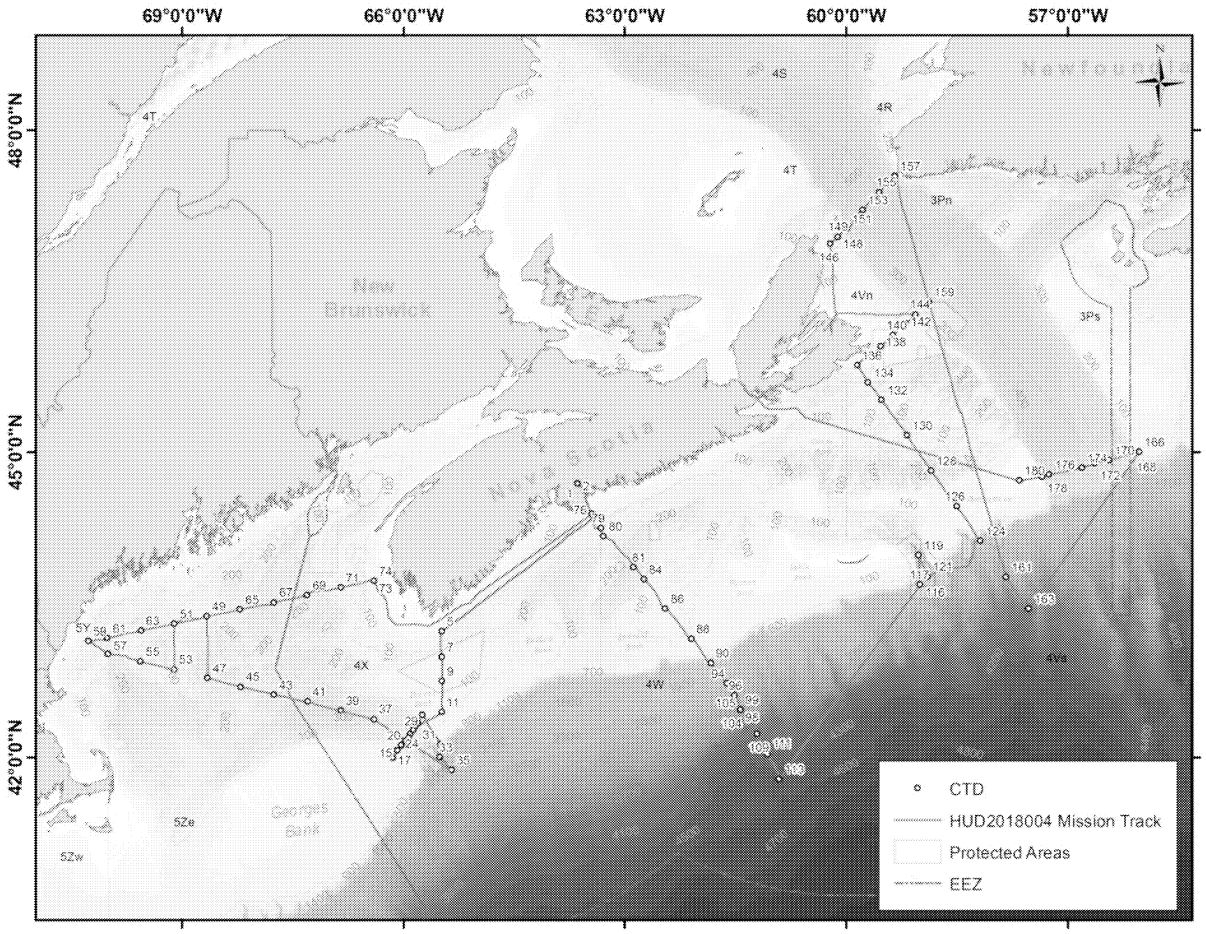


Figure 4. Locations for the 95 CTD casts during HUD2018004 AZMP spring survey. Each cast is labelled with the consecutive mission event.

Table 6. CTD casts during the HUD2018004 AZMP spring survey. The coordinates provided are in decimal degrees and reflect the ship's position at the time of deployment as recorded using the ELOG meta-data logger.

#	Event	Station	Date	Slat (DD)	Slon (DD)	Sounding (m)	pH	Water Collected	Aborted
1	1	HL_00	06/04/2018	44.6935	-63.6380	74	X		
2	2	HL_00	06/04/2018	44.6937	-63.6404	74	X		
3	5	BBL_01	08/04/2018	43.2513	-65.4801	63	X	X	
4	7	BBL_02	08/04/2018	43.0000	-65.4797	120	X	X	
5	9	BBL_03	08/04/2018	42.7581	-65.4789	104	X	X	
6	11	BBL_04	08/04/2018	42.4495	-65.4837	103	X	X	
7	12	PS_03	08/04/2018	42.2998	-65.8419	214	X	X	
8	13	PS_05	08/04/2018	42.2358	-65.9038	237	X	X	
9	14	PS_07	08/04/2018	42.1654	-65.9704	225	X	X	
10	15	PS_09	08/04/2018	42.0647	-66.0841	97	X	X	
11	17	PS_10	08/04/2018	41.9927	-66.1478	94	X	X	
12	20	PS_08	08/04/2018	42.1167	-66.0320	212	X	X	
13	22	PS_06	09/04/2018	42.1913	-65.9264	227	X	X	
14	24	PS_04	09/04/2018	42.2728	-65.8693	228	X	X	
15	27	PS_02	09/04/2018	42.3383	-65.8089	205	X	X	
16	29	PS_01	09/04/2018	42.4213	-65.7401	101	X	X	
17	31	BBL_05	09/04/2018	42.1293	-65.4970	192	X	X	
18	33	BBL_06	09/04/2018	41.9976	-65.5110	1100	X	X	
19	35	BBL_07	09/04/2018	41.8675	-65.3498	1885		X	
20	37	PL_09	10/04/2018	42.3797	-66.4012	271	X	X	
21	39	PL_08	10/04/2018	42.4638	-66.8512	329	X	X	
22	41	PL_07	10/04/2018	42.5544	-67.3013	301	X	X	
23	43	PL_06	10/04/2018	42.6252	-67.7540	203	X	X	
24	45	PL_05	10/04/2018	42.7031	-68.2051	186	X	X	
25	47	PL_04	10/04/2018	42.7899	-68.6553	204	X	X	
26	49	YL_06	11/04/2018	43.3990	-68.6650	148	X	X	
27	51	YL_07	11/04/2018	43.3295	-69.1052	154	X	X	

#	Event	Station	Date	Slat (DD)	Slon (DD)	Sounding (m)	pH	Water Collected	Aborted
28	53	PL_03	11/04/2018	42.8760	-69.1079	181	X	X	
29	55	PL_02	11/04/2018	42.9544	-69.5603	169	X	X	
30	57	PL_01	11/04/2018	43.0314	-70.0013	155	X	X	
31	59	YL_10	11/04/2018	43.1567	-70.2726	127	X	X	
32	61	YL_09	11/04/2018	43.1862	-70.0097	90	X	X	
33	63	YL_08	11/04/2018	43.2583	-69.5564	152	X	X	
34	65	YL_05	12/04/2018	43.4688	-68.2140	184	X	X	
35	67	YL_04	12/04/2018	43.5388	-67.7544	244	X	X	
36	69	YL_03	12/04/2018	43.6105	-67.3038	243	X	X	
37	71	YL_02	12/04/2018	43.6808	-66.8524	131	X	X	
38	73	YL_01	12/04/2018	43.7506	-66.4006	80	X		X
39	74	YL_01	12/04/2018	43.7505	-66.4009	83	X	X	
40	76	HL_01	13/04/2018	44.4007	-63.4493	87	X	X	
41	79	HL_02	13/04/2018	44.2660	-63.3199	156	X	X	
42	80	HL_02.25	13/04/2018	44.1858	-63.2886	181	X		
43	81	HL_03	13/04/2018	43.8847	-62.8850	269	X	X	
44	84	HL_03.3	13/04/2018	43.7612	-62.7439	206	X	X	
45	86	HL_04	13/04/2018	43.4759	-62.4548	86	X	X	
46	88	HL_05	13/04/2018	43.1804	-62.0979	104	X	X	
47	90	HL_05.5	14/04/2018	42.9402	-61.8326	458	X	X	
48	92	HL_06	14/04/2018	42.8300	-61.7328	1112	X	X	
49	94	HL_06.3	14/04/2018	42.7342	-61.6159	1680		X	
50	96	HL_06.7	14/04/2018	42.6179	-61.5171	2320		X	
51	98	HL_07	14/04/2018	42.4746	-61.4339	2760			X
52	99	HL_07	14/04/2018	42.4747	-61.4336	2760			X
53	100	HL_07	15/04/2018	42.4751	-61.4333	2797			X
54	101	HL_07	15/04/2018	42.4725	-61.4327	2774			X
55	102	HL_07	15/04/2018	42.4745	-61.4338	2768			X
56	103	HL_07	15/04/2018	42.4747	-61.4338	2779			X
57	104	HL_07	15/04/2018	42.4770	-61.4323	2759			X

#	Event	Station	Date	Slat (DD)	Slon (DD)	Sounding (m)	pH	Water Collected	Aborted
58	105	HL_07	15/04/2018	42.4762	-61.4336	2761		X	
59	107	HL_08	15/04/2018	42.3801	-61.3027	3380		X	
60	109	HL_09	15/04/2018	42.2328	-61.2104	3818		X	
61	111	HL_10	16/04/2018	42.0313	-61.0649	4075		X	
62	113	HL_11	16/04/2018	41.7753	-60.9110	4431		X	
63	116	SG_28	17/04/2018	43.7102	-59.0014	852	X		X
64	117	SG_28	17/04/2018	43.7109	-59.0002	834	X	X	
65	119	GULD_03	17/04/2018	44.0013	-59.0214	435	X	X	
66	121	GULD_04	17/04/2018	43.7897	-58.9005	2046		X	
67	124	LL_07	17/04/2018	44.1383	-58.1881	500	X	X	
68	126	LL_06	18/04/2018	44.4760	-58.5049	68	X	X	
69	128	LL_05	18/04/2018	44.8158	-58.8502	253	X	X	
70	130	LL_04	18/04/2018	45.1579	-59.1751	108	X	X	
71	132	LL_03	18/04/2018	45.4916	-59.5183	142	X	X	
72	134	LL_02	18/04/2018	45.6590	-59.7017	139	X	X	
73	136	LL_01	18/04/2018	45.8253	-59.8492	96	X	X	
74	138	STAB_01	18/04/2018	46.0006	-59.5330	64	X	X	
75	140	STAB_02	18/04/2018	46.1084	-59.3656	67	X	X	
76	142	STAB_03	18/04/2018	46.2179	-59.1952	93	X	X	
77	144	STAB_04	19/04/2018	46.3005	-59.0632	165	X	X	
78	146	CSL_01	20/04/2018	46.9588	-60.2157	84	X	X	
79	148	CSL_02	20/04/2018	47.0210	-60.1183	183	X		X
80	149	CSL_02	20/04/2018	47.0232	-60.1152	189	X	X	
81	151	CSL_03	20/04/2018	47.0987	-59.9920	322	X	X	
82	153	CSL_04	21/04/2018	47.2702	-59.7765	486	X	X	
83	155	CSL_05	21/04/2018	47.4328	-59.5572	486	X	X	
84	157	CSL_06	21/04/2018	47.5826	-59.3417	269	X	X	
85	159	STAB_05	21/04/2018	46.4176	-58.8822	376	X	X	
86	161	LL_08	22/04/2018	43.7832	-57.8332	2890		X	
87	163	LL_09	22/04/2018	43.4735	-57.5266	3722		X	

#	Event	Station	Date	Slat (DD)	Slon (DD)	Sounding (m)	pH	Water Collected	Aborted
88	166	BP_00	23/04/2018	45.0007	-56.0261	104	X	X	
89	168	BP_01	23/04/2018	44.9803	-56.1407	225	X	X	
90	170	BP_04	23/04/2018	44.9206	-56.4394	392	X	X	
91	172	BP_05	23/04/2018	44.8894	-56.6301	414	X	X	
92	174	BANQ_B6	23/04/2018	44.8471	-56.8085	427	X	X	
93	176	BANQ_B4	23/04/2018	44.7800	-57.2504	405	X	X	
94	178	BANQ_B3	23/04/2018	44.7622	-57.3492	77	X	X	
95	180	BANQ_B1	23/04/2018	44.7195	-57.6554	36	X	X	

Oxygen

The oxygen data collected by the CTD sensors and Winkler titration method will be used to create new calibration coefficients before the final run of the CTD processing. It will be necessary to extract these corrected oxygen values when they are produced so they can be accurately reflected in our data archives.

The adjusted Soc values are calculated by a 2 step process. First, a "threshold field" is produced that subtracts the mean difference between the sensor and the average Winkler value for all samples, from the individual sample difference between the sensor and Winkler:

(SBE O2 – Winkler O2) - mean(SBE O2 – Winkler O2)

The next step calculates a new slope term by using the following equation:

NewSoc = mean(previousSoc*([Winkler O2]/[SBE O2]))

From events 001 to 113 (HL_11), the oxygen sensors #0133 (primary – calibrated on Dec 1/17) and #0042 (secondary – calibrated on Dec 19/17) were deployed on the CTD. In deep water casts (below 1000 m), the primary oxygen sensor was displaying periodic oscillations that were not evident in the secondary. The decision was made to remove the primary after event 113 and replace it with #3030, but the oscillations continued. Finally, after event 159 (STAB_05), the SBE 9 (#1214) was replaced with #0370 and the problem observed in Figure 5 was resolved. Note that the mean oxygen concentration during these oscillations seemed in line with conditions above and below. While it is recommended that the secondary oxygen should be utilized to interpret water column conditions, the primary data should not be thrown out.

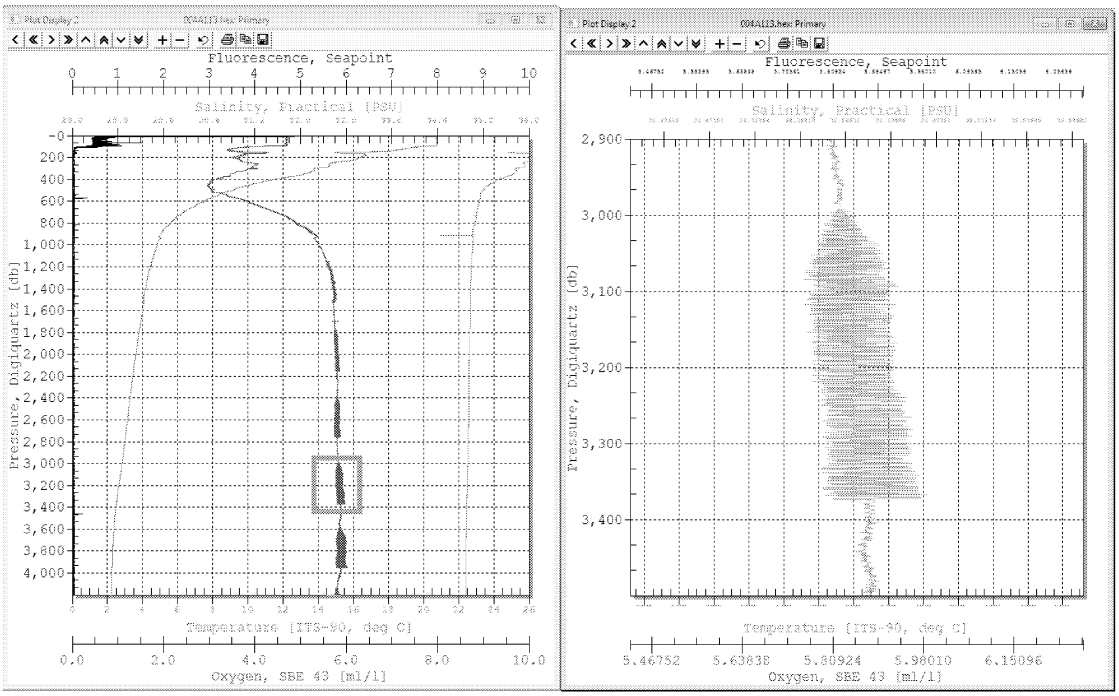


Figure 5. The periodic deep water voltage oscillations observed for the primary oxygen sensors from events 001 to 159.

The first step was to compare the Winkler replicates throughout the mission and remove any outlier data rows from further analysis (Figure 6.). In total, 12 of the total 80 (15%) rows where Winkler replicates were taken during the mission were removed prior to proceeding

The analysis below is broken in to 2 parts for each of the primary sensors (#0133 and #3030). The oxygen report dataset was split into 2 subsets, <= event 113 and >= event 113.

Events 005 to 113

Before the Soc can be calculated, some basic comparisons between the primary (#0133) and secondary (#0042) sensors for the first subset were completed to remove outliers and bad data (Figure 7). The 1.5 * inter quartile range was used to determine "outlier" data that could bias the results. From event 5 (BBL_01) to event 31 (BBL_05), there were many outliers between the primary and secondary sensor. This was driven by a malfunctioning secondary oxygen sensor that self-corrected after event 31 (Figure 8).

The "threshold fields" were calculated for the both the primary (#0133) and secondary (#0042) sensors (Figures 9 and 10). Twelve more data rows were removed during the primary threshold calculation (Figure 9) before proceeding to secondary threshold calculations (Figure 10). The primary and secondary threshold calculations remove 13 additional rows of data.

Table 7 shows the previous and revised Soc values for the primary and secondary oxygen sensors (#0133 and #0042) between events 005 and 113. The ratio of the new and old Soc values was calculated for each sensor.

The original outlier free primary and secondary sensor values were then multiplied by their new corresponding Soc ratios to produce corrected primary and secondary sensor values (Figures 11 and 12) that more closely matched corresponding Winkler values. The difference between the primary and secondary sensors after correction (Figure 13) was slightly improved by the revised Soc values.

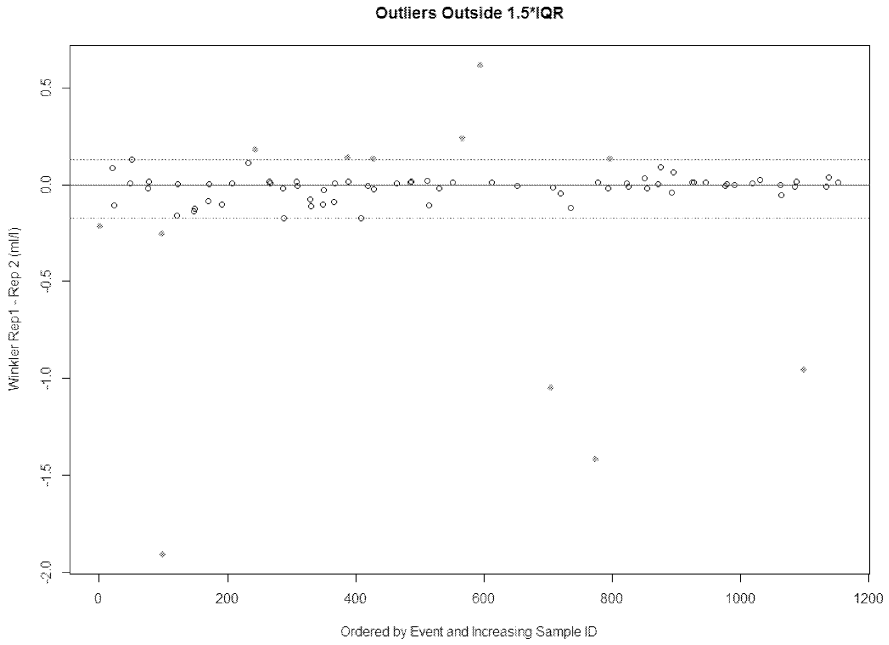


Figure 6. In total, 12 of 80 (15%) Winkler replicates were considered outliers and removed from further analysis. The mean difference between replicates was nearly zero at 4.4e-16.

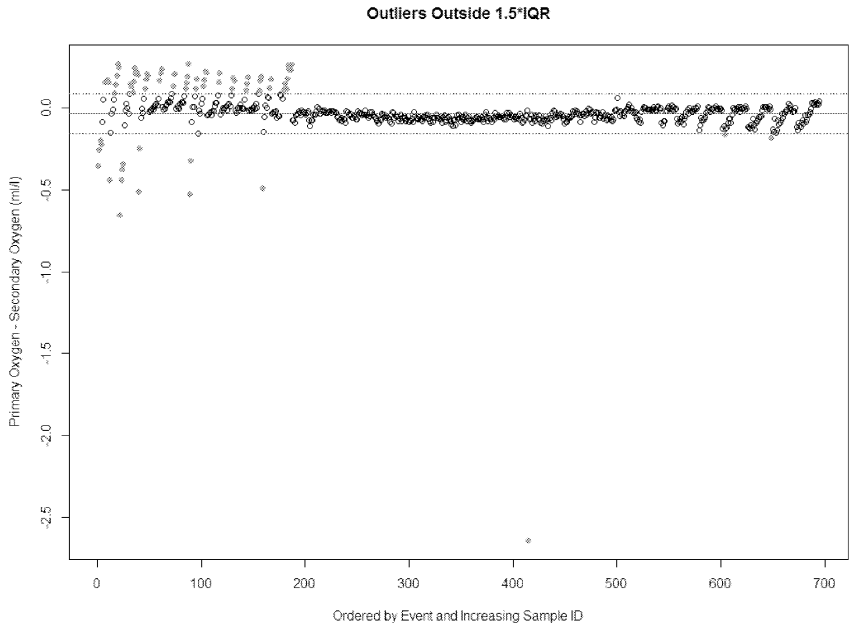


Figure 7. The difference between primary oxygen sensor #0133 and secondary oxygen sensor #0042 for events 005 - 113. The mean difference before outlier removal (solid blue line) is ~ -0.04 ml/l. ~96% of the outlier difference between the primary and secondary were observed between events 5 and 31.

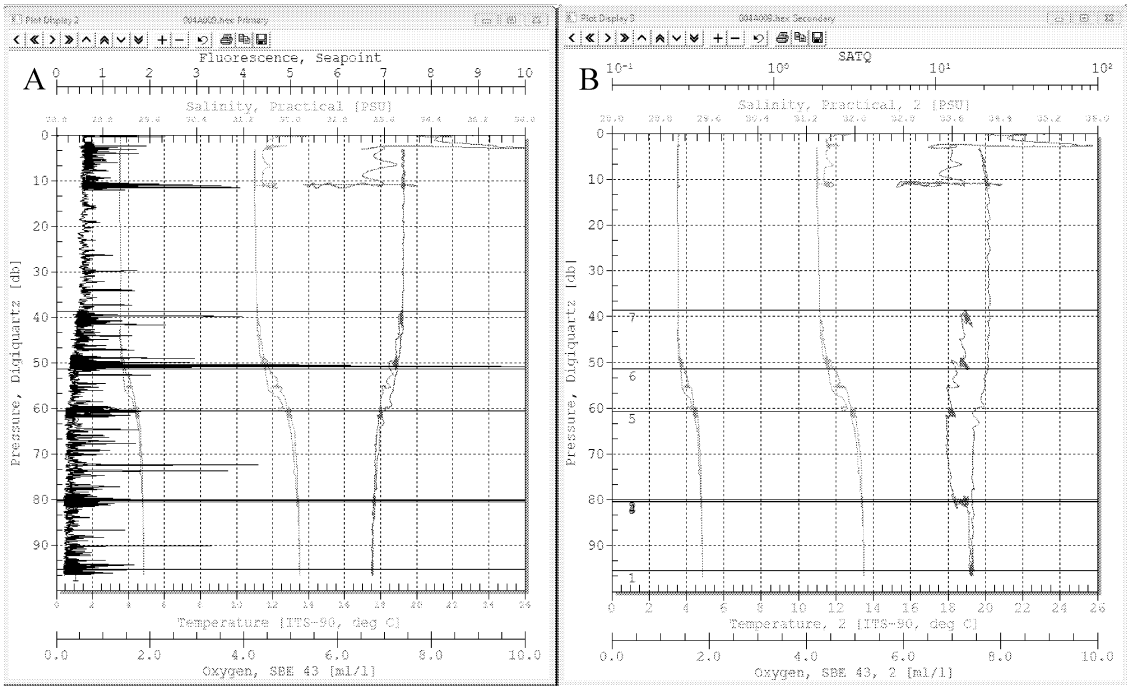


Figure 8. The primary oxygen sensor (A – blue line #0133) has a matching up and down trace. The secondary sensor (B – blue line #0042) overestimated on the down cast and came back to values similar to the primary on the up cast. This occurred between events 005 and 030 but then self-corrected for the remainder of the mission.

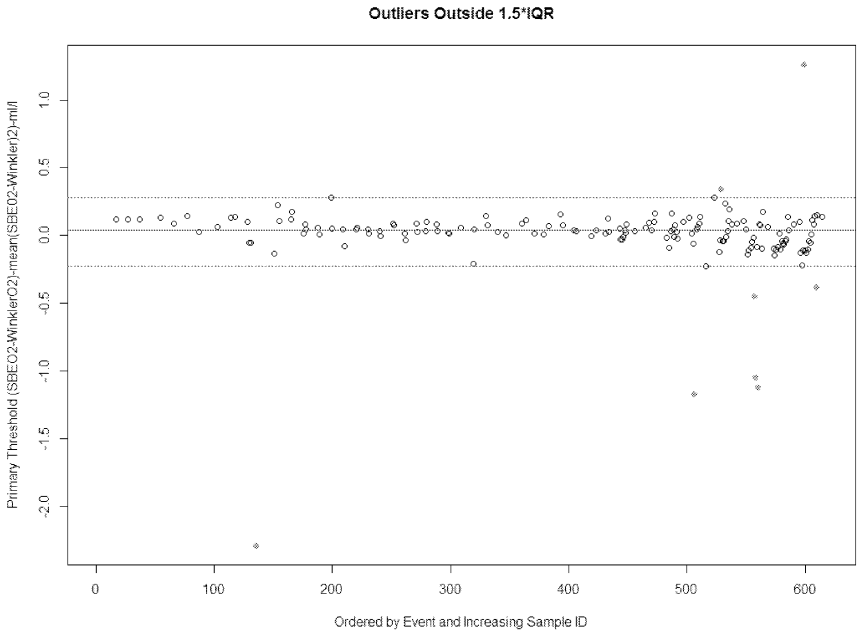


Figure 9. Seven outlier "threshold" field values were removed for the primary (#0133) sensor after other outlier data (i.e., Winkler and sensor differences) were removed.

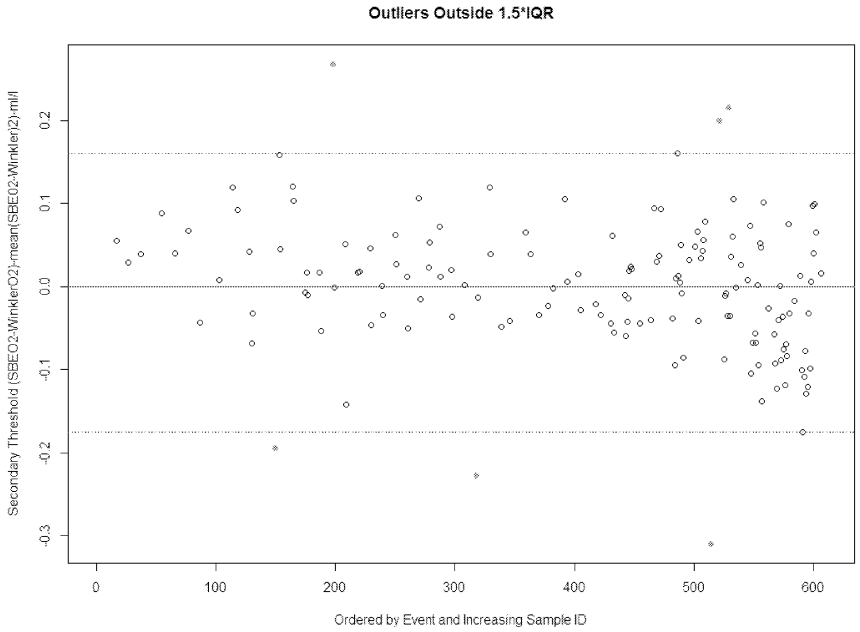


Figure 10. An additional 6 outlier "threshold" field values for the secondary sensor were removed and all of the remaining data were used to calculate the Soc value.

Table 7. Previous and New Soc values for the primary and secondary SBE Oxygen sensors from events 005 to 113.

	Old Soc	**New Soc**	**Ratio (New:Old)**
Primary Sensor #0133	4.0488e-1	4.213026e-1	1.040562
Secondary Sensor #0042	4.3400e-1	4.475889e-1	1.030598

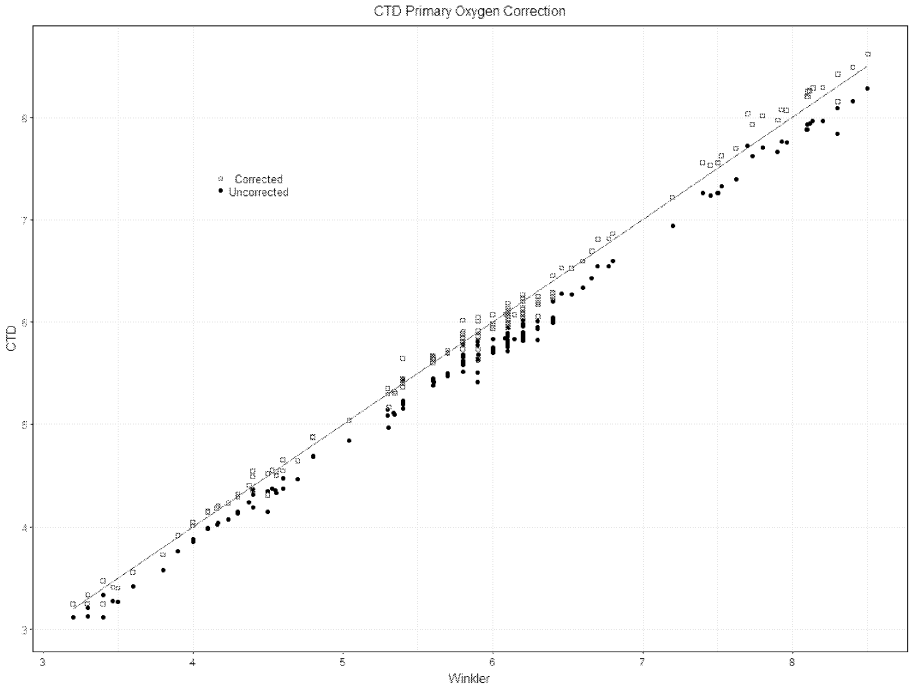


Figure 11. Black dots – uncorrected outlier free sprimary sensor values (#0133) and Blue squares – Soc corrected primary sensor values.

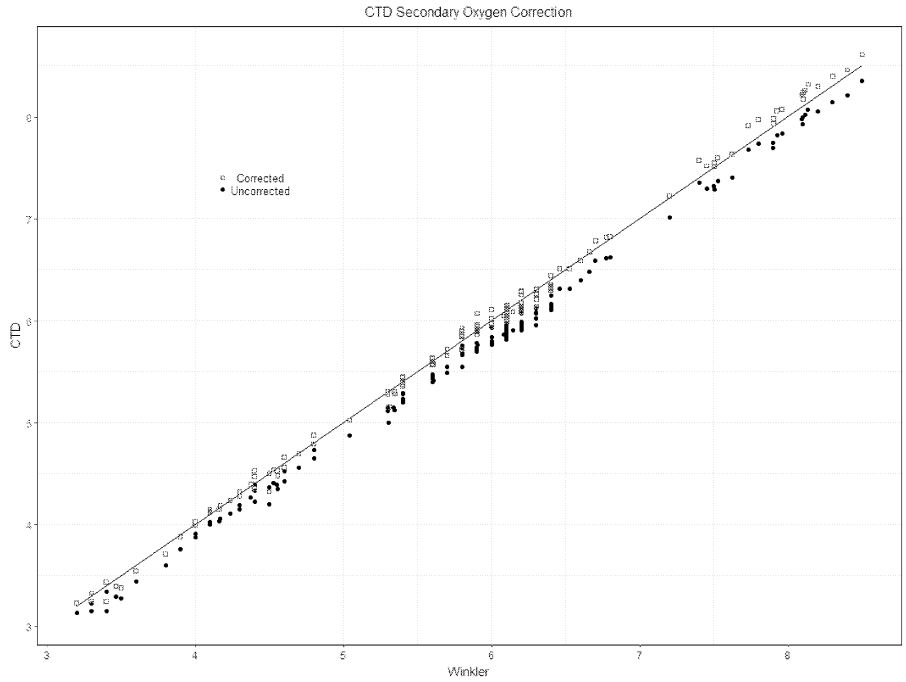


Figure 12. Black dots – uncorrected outlier free secondary sensor values (#0042) and Blue squares – Soc corrected secondary sensor values.

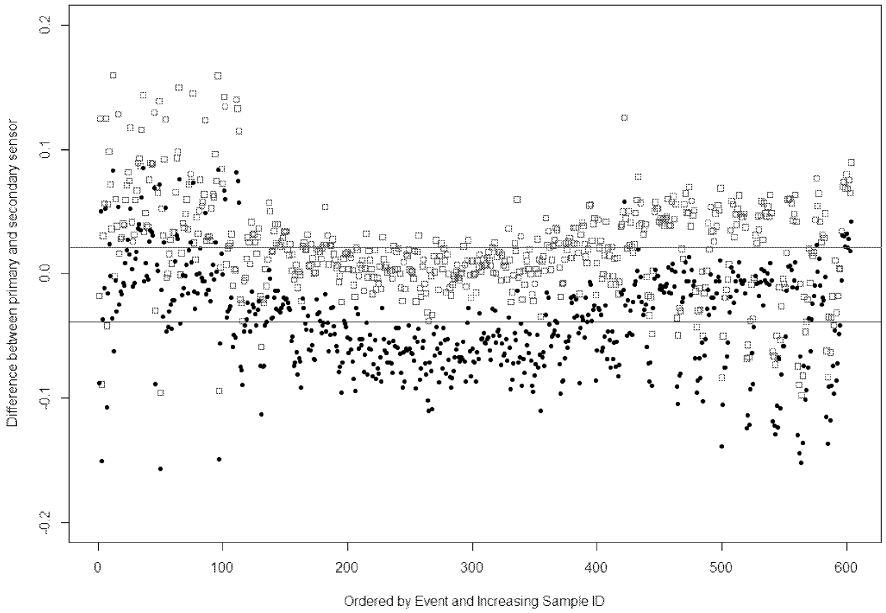


Figure 13. Black dots – uncorrected difference between primary (#0133) and secondary sensors (#0042) between events 005 and 113 (mean = -3.8866e-002 ml/l). Blue squares – corrected difference between the primary and secondary sensors (mean = 2.0948e-002).

Events 117 to 180

Comparisons between the primary (#3030) and secondary (#0042) sensors for the second subset were completed to remove outliers and bad data (Figure 14). From event 117 (SG_28) to event 180 (BANQ_B1), there were 17 outliers between the primary and secondary sensor (Figure 14). Of these, 12/17 were from event 146 at CSL_01, where the secondary oxygen sensor malfunctioned throughout the cast. These data points were removed before proceeding to the threshold step.

The "threshold fields" were calculated for the both the primary (#3030) and secondary (#0042) sensors (Figures 15 and 16). Six data rows were removed during the primary threshold calculation (Figure 15) before proceeding to secondary threshold calculations (Figure 16), where no further threshold outliers were observed.

Table 8 shows the previous and revised Soc values for the primary and secondary oxygen sensors (#3030 and #0042) between events 117 and 180. The ratio of the new and old Soc values was calculated for each sensor.

The original outlier free primary and secondary sensor values were then multiplied by their new corresponding Soc ratios to produce corrected primary and secondary sensor values (Figures 17 and 18) that more closely matched corresponding Winkler values. The calculated Soc for the secondary sensor (#0042) for each event subset is very similar (Tables 7 and 8), which shows that this sensor was fairly constant throughout the mission. Figure 19 shows the difference between the primary and secondary sensors after correction for this range of events.

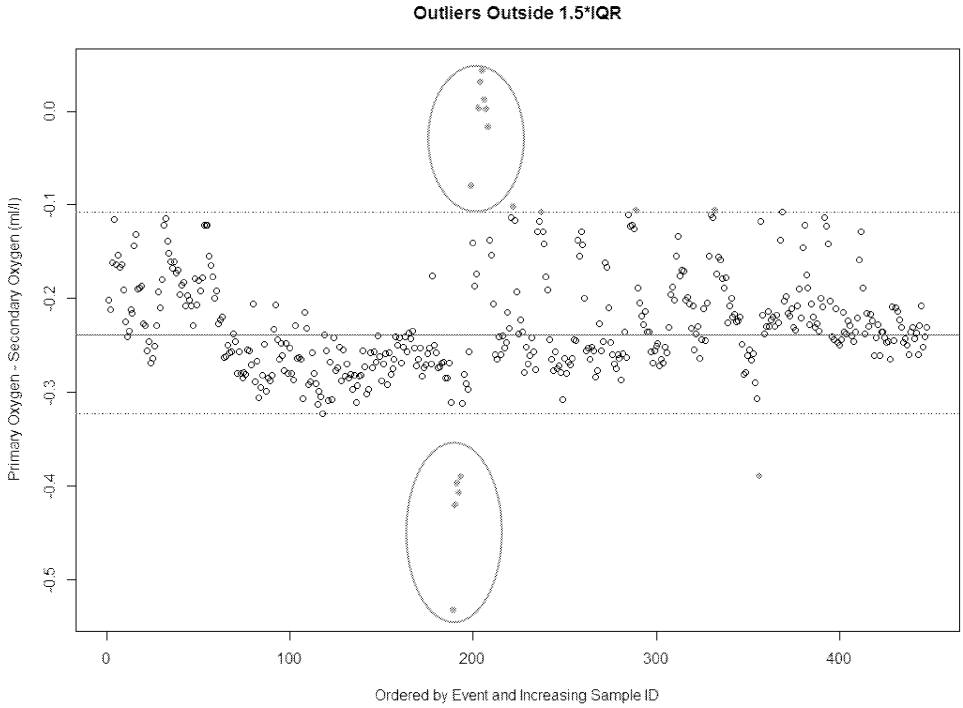


Figure 14. Twelve of the 17 outliers between the primary (#3030) and secondary (#0042) oxygen sensors occurred during event 146 at CSL_01 (red circles).

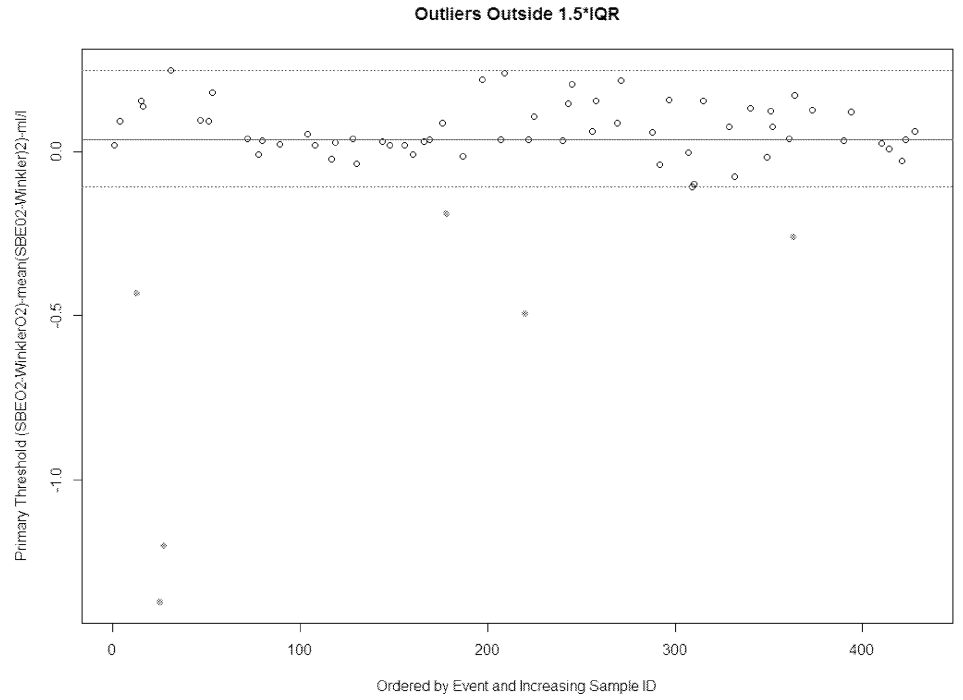


Figure 15. Six outlier "threshold" field values were removed for the primary (#3030) sensor after other outlier data (i.e., Winkler and sensor differences) were removed.

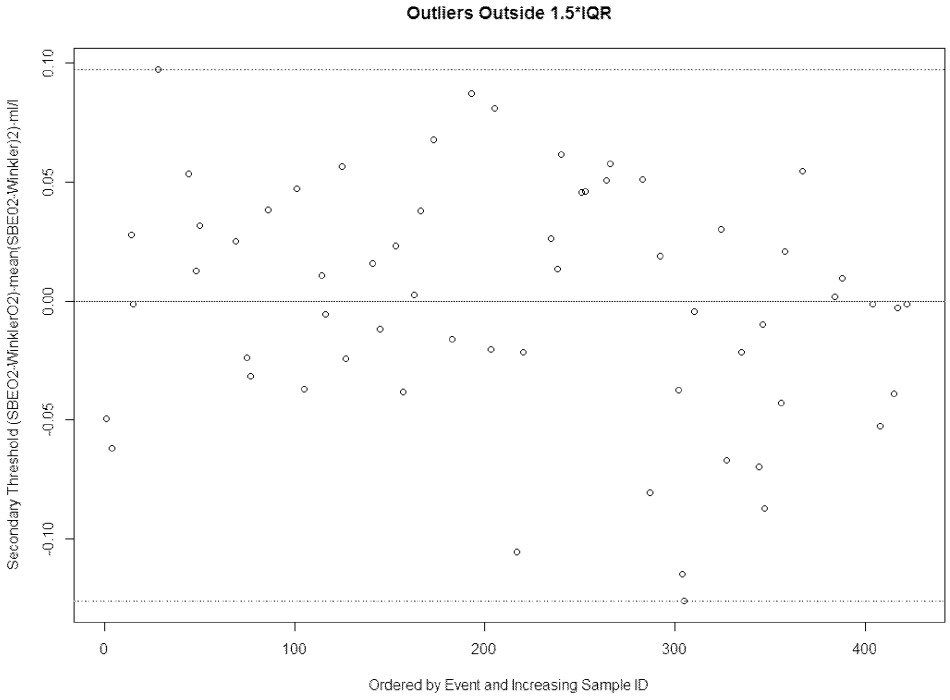


Figure 16. No additional "threshold" field values for the secondary sensor were removed.

Table 8. Previous and New Soc values for the primary and secondary SBE Oxygen sensors from events 117 to 180.

	Old Soc	**New Soc**	**Ratio (New:Old)**
Primary Sensor #3030	4.5600e-1	4.872490e-1	1.068529
Secondary Sensor #0042	4.3400e-1	4.488096e-1	1.033409

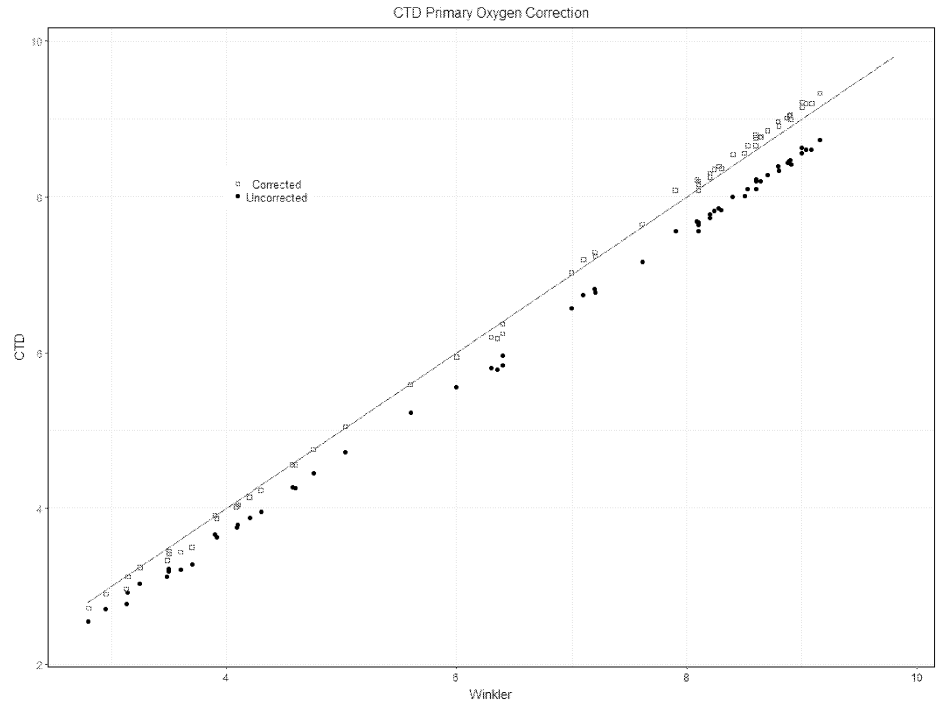


Figure 17. Black dots – uncorrected outlier free primary sensor values (#3030) and Blue squares – Soc corrected primary sensor values.

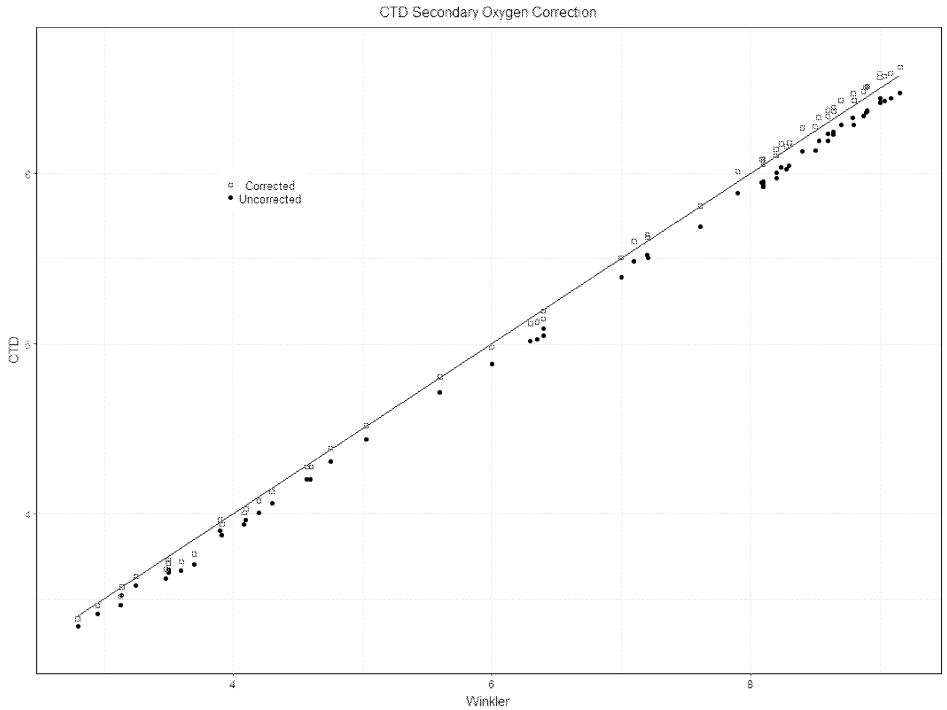


Figure 18. Black dots – uncorrected outlier free secondary sensor values (#0042) and Blue squares – Soc corrected secondary sensor values.

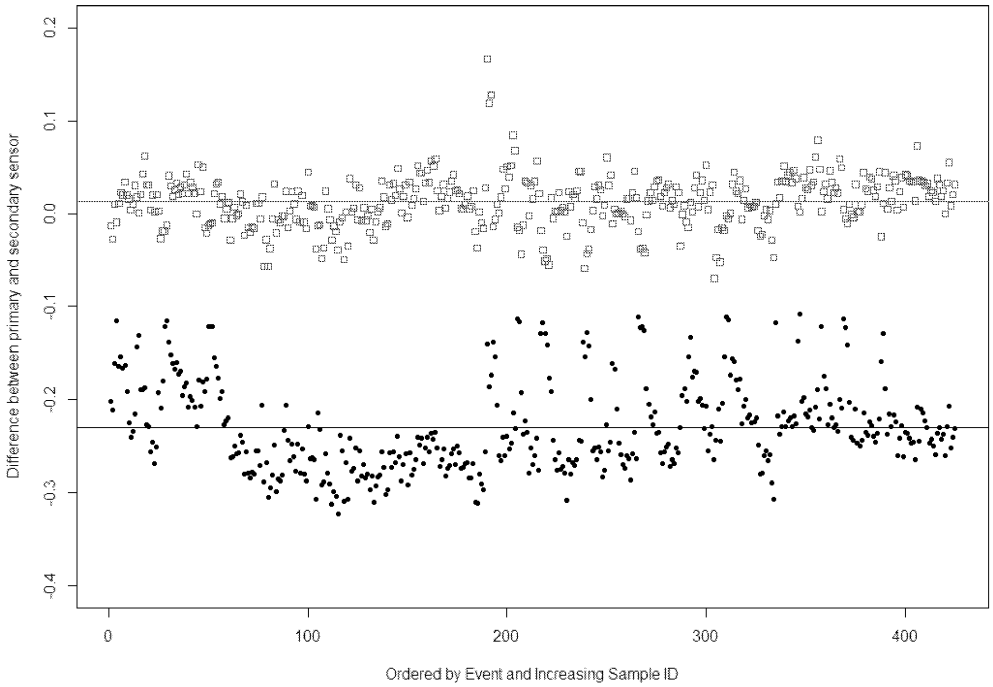


Figure 19. Black dots – uncorrected difference between primary (#3030) and secondary sensors (#0042) between events 117 and 180 (mean = -2.3013e-001 ml/l). Blue squares – corrected difference between the primary and secondary sensors (mean = 1.2820e-002).

Salinity

(With portions extracted from HUD2014017 Cruise Report)

Conductivity Calibration

The salinometer outputs the conductivity as a ratio with the standard; therefore, some conversions are done to get the conductivity of the bottle. The standard has a given K15 value:

K15 = conductivity of standard seawater at 15°C and 1 atm/conductivity of KCl solution (32.4356g/kg) at 15°C and 1 atm.

Where K15 = 0.99984 for this particular standard and the conductivity of KCl standard = 4.29140 S/m and can be found in the seawater Matlab package (gsw_C3515 function). Knowing K15 and the conductivity of the KCl solution, the conductivity of the standard seawater can be determined. Then, by multiplying by the conductivity ratio from the salinometer, the conductivity of the sample can be determined.

It should be noted that these samples were analyzed with a bath temperature of 24°C rather than the 15°C that the standard conductivity was defined. The salinometer program accounted for this temperature difference so that the output sample conductivity ratios with the standard are at 15°C.

Now we have the conductivity of the sample at 15°C and at the pressure of the bath in the salinometer; however, this needs to be converted to conductivity at the temperature and pressure of the CTD. This can be done using some functions from the same Matlab package.

First calculate the salinity of the bottle using the conductivity and pressure from the salinometer and a temperature of 15°C.

Salinity_bottle = gsw_SP_from_C(Conductivity_salinometer[mS/cm],T[C],P_bath)

Then re-calculate the conductivity from this salinity value using temperature and pressure from the CTD.

Conductivity_bottle = gsw_C_from_SP(Salinity_bottle,T_CTD,P_CTD) %[mS/cm]

This now gives conductivity values that can be compared to the CTD values. To correct the CTD conductivity a linear regression is done on this equation:

Bottle_conductivity = b1 + b2*CTD_conductivity

to find an intercept, b1, and slope, b2, that will make the CTD conductivity better match the bottle conductivity.

First, a comparison of the primary (#3562, Calibrated December 7, 2017) and secondary (#1076, Calibrated December 6, 2017) sensor data (P.S.U.) was performed to highlight

and remove any outliers beyond 1.5 * the inter-quartile range of the data (Figure 20). This revealed 55 outliers that were removed from the analysis. Next, the difference between the primary sensor and salinometer values was compared in a similar manner to identify outliers that should be removed from analysis (Figure 21) (n=29). The same process was completed for the secondary sensor, and a single outlier was identified and removed before proceeding (Figure 22). After outliers were removed, it was determined that the primary and secondary salinometers were on average -0.0012 and 0.0015 P.S.U different from their corresponding salinometer values throughout the mission (Figure 23).

At this point the swCSTp function, which uses the Gibbs-Sea Water (gsw_C_from_SP) formulation, from the R OCE package, is used to convert the salinity of the bottle sample to conductivity. The data were filtered and used to create a linear regression for both the primary and secondary CTD sensor conductivity cells. The intercept (b1) and slope (b2) values for both regressions were extracted from the linear regression summary and used to correct the sensor values. These terms were used to calibrate the sensor salinity values for CTD output files prior to data archiving (Table 9). Figure 24, shows the difference between the primary and secondary sensors both before and after calibration with the new coefficients applied.

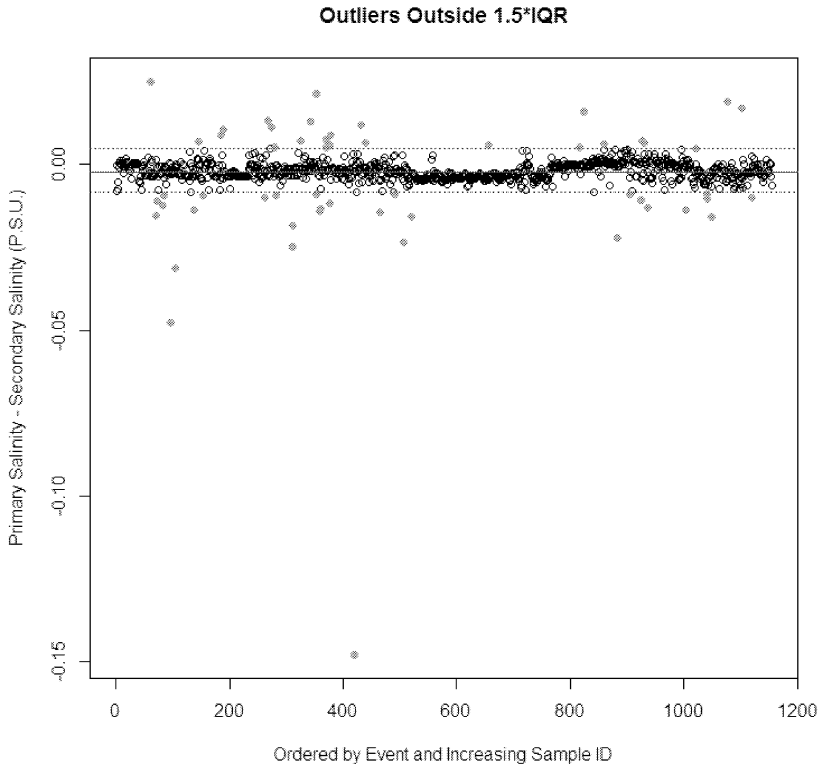


Figure 20. The outlier sensor values (red dots) that were removed prior to further analysis (n=55). The average difference between the primary (#3562) and the secondary (#1076) was ~-0.0022 P.S.U. throughout the mission.

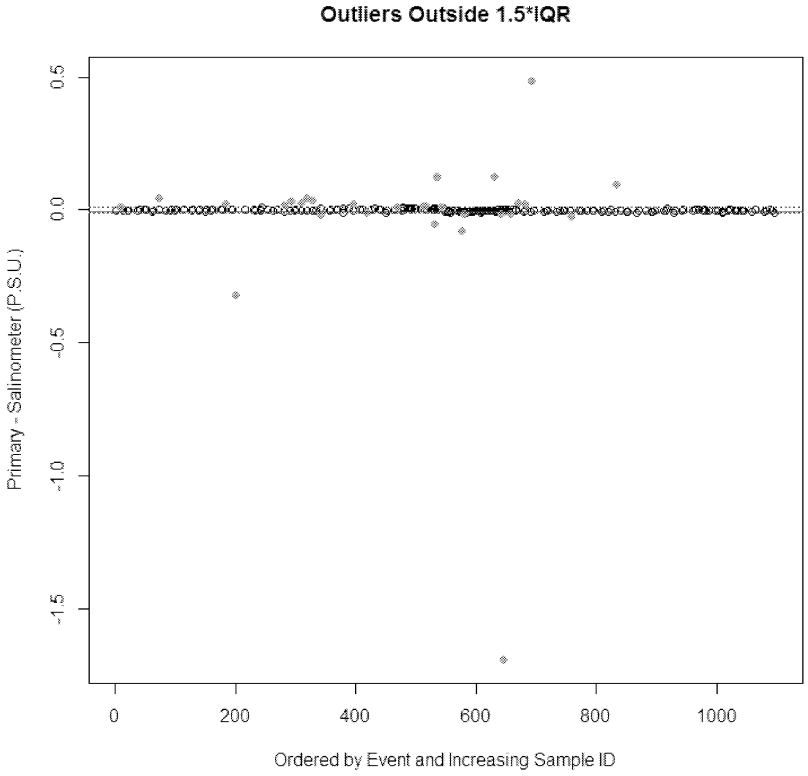


Figure 21. The outlier differences between the primary sensor and the salinometer values (red dots) are removed prior to further analysis (n=29).

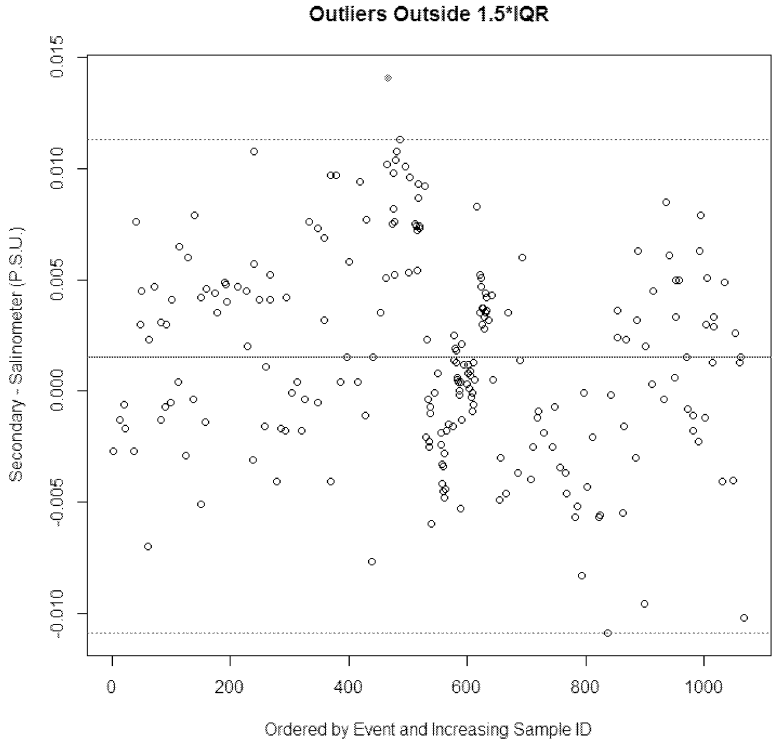


Figure 22. The outlier differences between the secondary sensor and the salinometer values (red dots) were also removed (n=1).

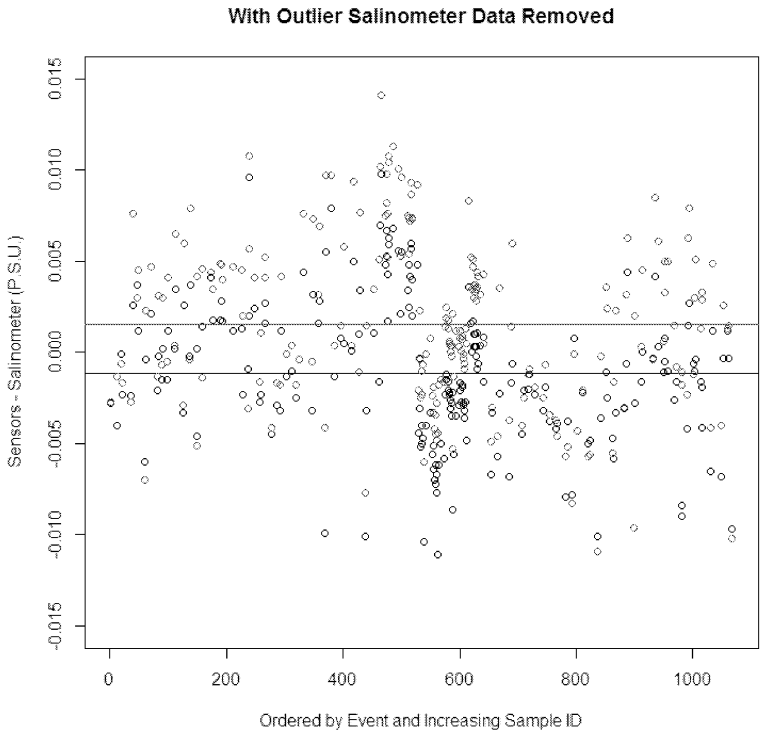


Figure 23. Note that after the outliers have been removed, the differences between the primary (#3562) and secondary (#1076) sensors and corresponding salinometer values are -0.0012 (black line) and 0.0015 (blue line) respectively.

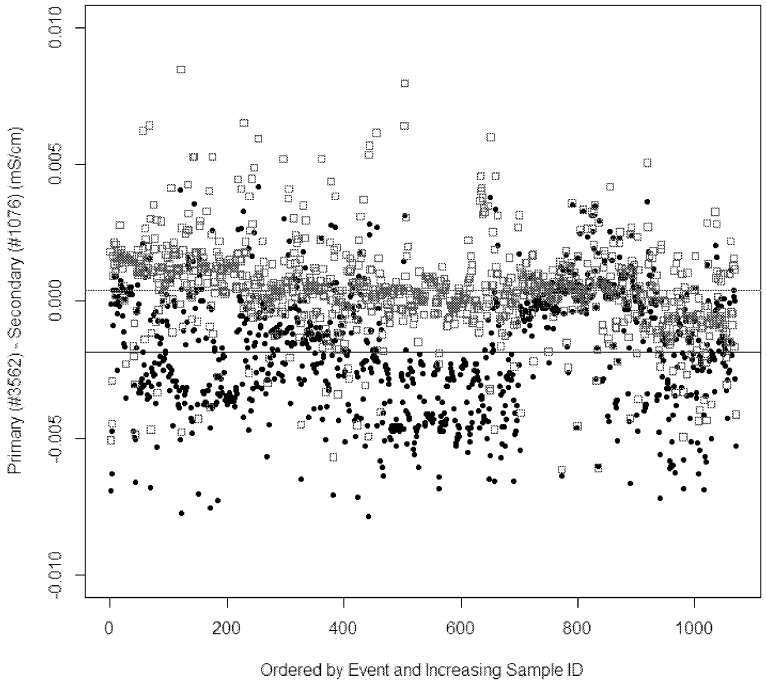


Figure 24. The mean difference between the primary (#3562) and secondary (#1076) conductivity values before correction was -0.00184 mS/cm (black) and after correction is 0.00042 mS/cm (blue).

Table 9. The revised intercept (b1) and slope (b2) terms calculated for both the primary (#3562) and secondary (#1076) conductivity sensors.

Conductivity Sensor	b1	b2
Primary (#3562)	7.5762e-03	0.999802
Secondary (#1076)	1.5085e-02	0.999504

Chlorophyll a

Throughout the mission, Chl a was measured in-situ via a SeaPoint fluorometer attached to the CTD rosette (Appendix 1a). Duplicate samples (n=668) were regularly taken for Chl a analysis with a Turner Fluormeter. A comparison of the replicates showed that while the mean difference between replicates was 3.1903e-003 µg/L, there were a total of 94 out of 668 replicates are considered outliers (Figure 25). Outliers were selected via the 1.5 * interquartile range (1.5 IQR) method discussed in the previous oxygen and salinity sections of this report. These outliers were removed before making the comparison between the SeaPoint sensor values and the Turner sensor values.

Similar outlier identification methodology was employed to remove data that showed larger than expected differences between the SeaPoint sensor and the Turner Fluorometer data (Figure 26). First, both the SeaPoint data and the Turner data were standardized by dividing both data sets by the SeaPoint data value. This made each SeaPoint data value for a bottle fire equal to 1, and the corresponding mean replicate Turner fluorometer value a percentage of the SeaPoint value. A value of 1.15 means that the Turner Fluorometer value was 15% greater than its corresponding SeaPoint value and a value of 0.85 means that the Turner value was 15% less than the SeaPoint value. This was done, because calculating the straight difference between values was influenced greatly by their magnitude. The difference between 0.01 and 0.1 and the difference between 6.31 and 6.4 are both 0.09, but the relative difference is ~90% and ~1.4 % respectively. Figure 26 shows the outliers calculated in this way. Out of 574 comparisons between the CTD sensor and the mean of the Turner Fluorometer replicates, 50 outliers were identified and removed before proceeding. The blue line shows that on average, SeaPoint sensor concentration values are ~68.2 % less than corresponding Turner fluorometer values.

Figure 27 shows the log/log relationship between the SeaPoint Fluorometer values and the Mean Turner ChlA values with the outliers from Figure 26 highlighted in red. The black line corresponds to the 1:1 line. When the outliers are removed and a linear regression is applied to the log10/log10 linear relationship between the CTD sensor and the mean replicates (Figure 28), the relationship is strong and significant (R-squared: 0.8905, $p<2.2e-16$).

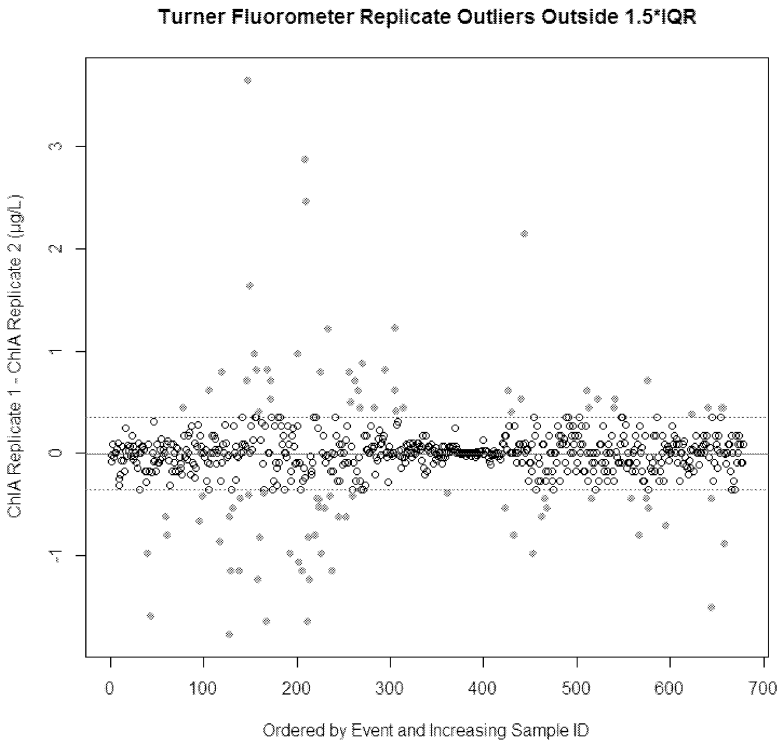


Figure 25. The outlier Turner replicates removed prior to determining the relationship between the Turner Fluorometer and SeaPoint sensor values (n=94).

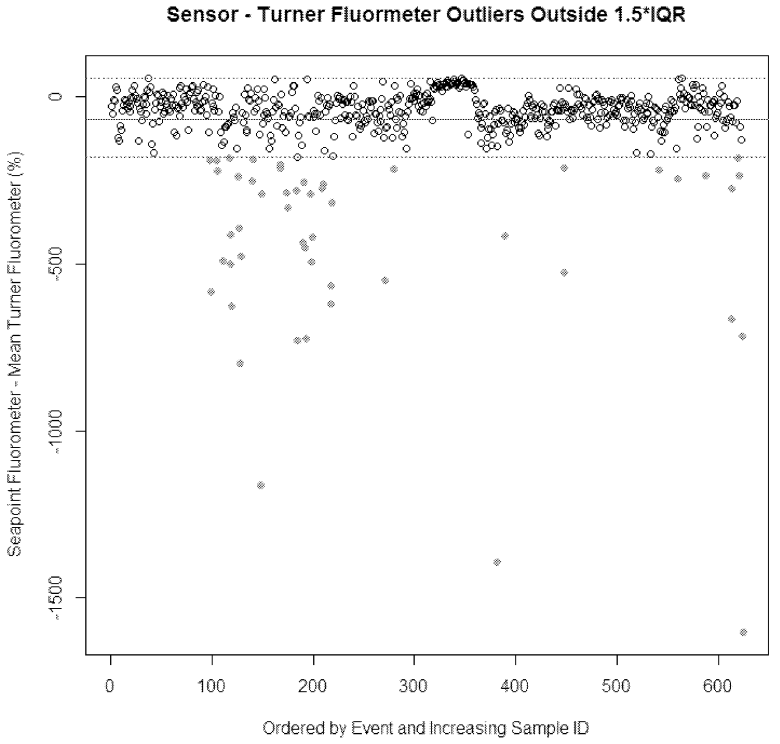


Figure 26. The outliers identified from calculating the % difference between Turner Fluorometer values and the SeaPoint sensor values (n=50).

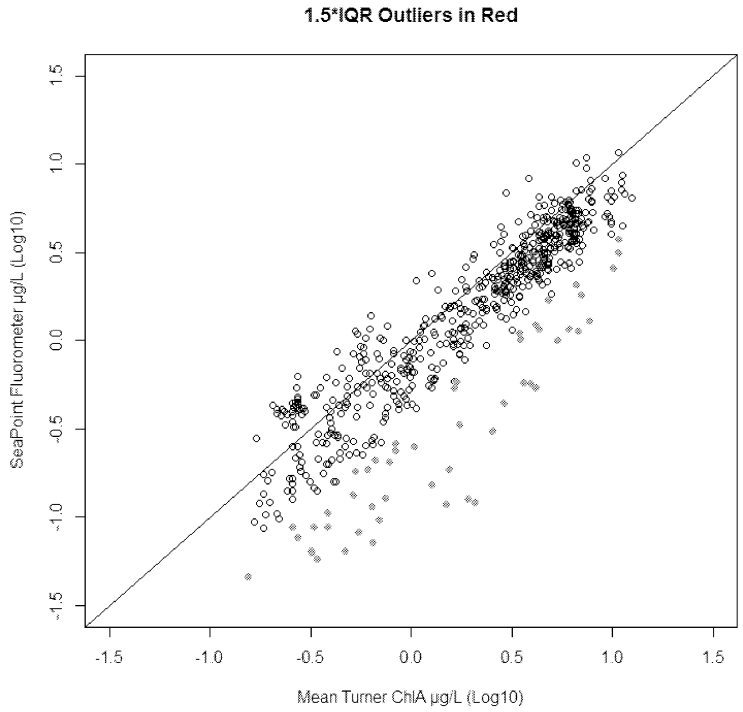


Figure 27. The log10 scale plot of SeaPoint Fluorometer values and the corresponding mean replicate Turner Fluorometer values. Note the highlighted 1.5 * IQR outliers from Figure 26 in red.

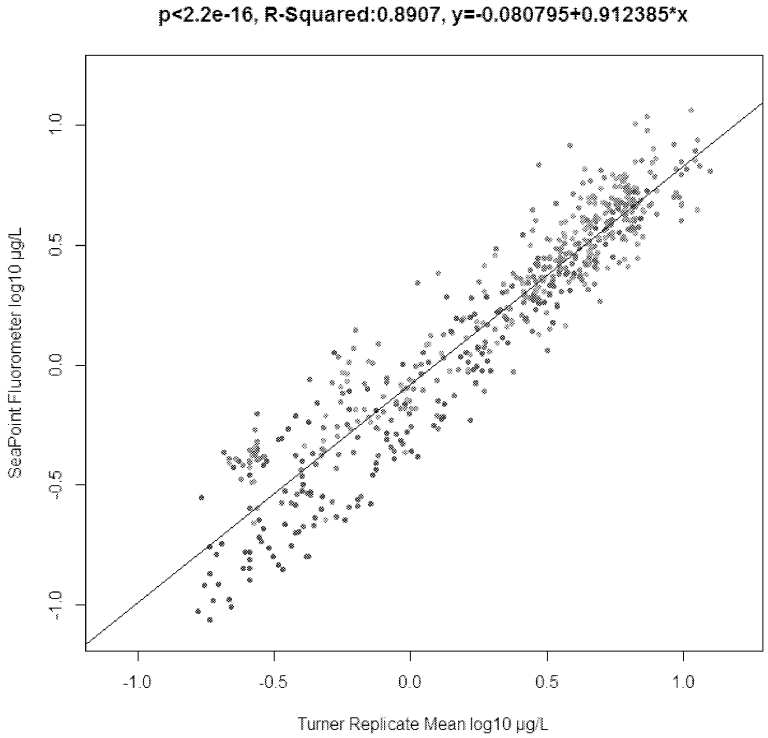


Figure 28. The log10/log10 plot of SeaPoint Fluorometer values and the corresponding mean replicate Turner Fluorometer values colour coded by depth, where red and dark red are shallow (closer to the surface) and purple and blue are deep (closer to 100 m).

Water Samples for Chemical Analyses

Station specific rosette bottle firing depths and water collections for chemical analysis can be found by referring to the CTD deck sheet binder and/or water chemistry sampling document prepared upon the conclusion of the mission and provided to ODIS. Table 6 highlights CTD casts where water collections were made.

Photosynthetically Active Radiation Sensor (PAR)

The CTD was outfitted with a Satlantic Cosine PAR (irradiance) sensor (#1043, calibrated December 1, 2015) enclosed in a 7000 m titanium housing. Unfortunately, it was determined that the sensor failed during event 98 at HL_07 and no spare was available, so there is no in water PAR data available after this.

pH Sensor

The pH sensor (#1129, calibrated February 12, 2018) was deployed on the rosette only when the maximum depth was less than or equal to ~1200 m. The CTD casts for which it was deployed are noted in Table 6. The sensor was included during the mission to support an ACCASP initiative investigating the delineation of ocean acidification and calcium carbonate saturation state of the Atlantic zone. The sensor will soon become part of the core AZMP suite of sensors.

Biological Program

Narrative

The "core" biological program conducted as part of cruise HUD2018004, with some modifications, was a continuation of studies began in pre-AZMP years to describe the large-scale (spatial and temporal) variability in plankton biomass, productivity and biogenic carbon inventories on the Scotian Shelf.

The program currently consists of essentially 3 elements:

1. mesozooplankton community structure, population growth and biomass, and
2. dissolved organic carbon measurements;
3. Pigment analysis and flow cytometry for assessment of phyto-, micro- and nano-plankton communities.

Table 6 provides a review of the stations where water samples were taken from rosette bottles for element 2 above. The mesoplankton sampling program is described below in more detail. This is followed by descriptions of "non-core" or ancillary biological sampling that includes a description of water sampling efforts in support of projects investigating how organic and organometallic micronutrients influence primary productivity and phytoplankton community structure on the Scotian Shelf (Erin Bertrand – Dalhousie University), and an assessment microbial communities and their associated processes (Julie LaRoche – Dalhousie University). The Biological Program section is concluded with a summary of pelagic seabird and marine mammal observations provided by Carina Gjerdrum of the Canadian Wildlife Service.

No integrated phytoplankton sampling took place during this mission.

The ultimate aim of "core" studies is twofold:

1. to provide a description of the inventories of biogenic carbon, their turnover rates and variability in space and time as part of Ocean Ecosystem Science Division's (OESD) continuing climate studies, and
2. to provide a description of plankton life-cycles and productivity on the Scotian Shelf and its influence or contribution to ecosystems in support of OESD's ecosystem-related research.

Mesozooplankton Sampling

Remarks/Comments

In order to estimate the mesozooplankton community abundance and biomass, a conical ring net of 202 µm mesh size with an aperture of 75 cm in diameter (filtering ratio 1:5) equipped with a KC Denmark flow-meter was towed vertically from the bottom to the surface at most stations (or from a maximum depth of 1000m – AZMP standard). In total, there were 85 vertical ring net tows during the mission (Table 10, Figure 29). Of these, 1 was a 76 µm mesh tow (30 cm diameter and 1:5 filtering ratio) at HL_02 (Events 78), and 29 were 202 µm mesh tows at core stations along core AZMP sections (HL, BBL and LL) (Table 10 - objective 1). The 76 µm net tows at HL_02 serve the same purpose of quantifying the community but targets a smaller fraction of the mesozooplankton community (i.e. smaller developmental stages, eggs and nauplii). Regardless of the mesh size, contents of the cod end were preserved in 4% buffered formaldehyde.

Table 10 provides a summary of the vertical net tow operations conducted throughout the mission and the objectives that they support.

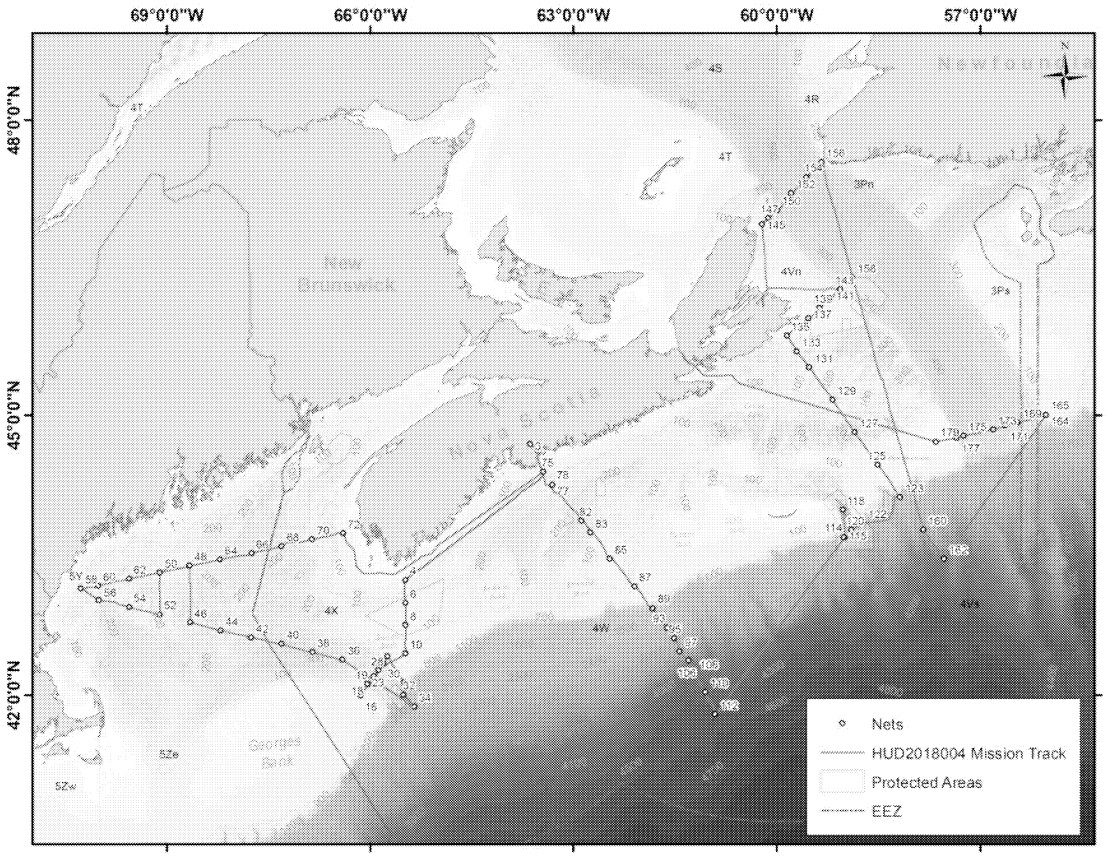


Figure 29. Locations for vertical ring net tows. Each tow is labelled with the consecutive mission event.

Table 10. Zooplankton collection activities during the HUD2018004 AZMP spring survey. The coordinates provided are in decimal degrees and reflect the ship's position at the time of deployment as recorded using the ELOG meta-data logger. Bolded rows represent aborted net tows.

#	Event	Date	Station	Operation	Mesh Size (µm)	Slat (DD)	SLong (DD)	Objective	Comment
1	3	07/04/2018	HL_00	RingNet	202	44.6935	-63.6402	Gear Testing	
2	4	08/04/2018	BBL_01	RingNet	202	43.2486	-65.4819	1	
3	6	08/04/2018	BBL_02	RingNet	202	43.0007	-65.4819	1	
4	8	08/04/2018	BBL_03	RingNet	202	42.7593	-65.4803	1	
5	10	08/04/2018	BBL_04	RingNet	202	42.4504	-65.4838	1	
6	16	08/04/2018	PS_10	RingNet	202	41.9932	-66.1464	4	
7	**18**	**08/04/2018**	**PS_08**	**RingNet**	**202**	**42.1184**	**-66.0368**	**4**	Aborted after mud found in sample.
8	19	08/04/2018	PS_08	RingNet	202	42.1163	-66.0363	4	
9	21	09/04/2018	PS_06	RingNet	202	42.2031	-65.9438	4	
10	23	09/04/2018	PS_04	RingNet	202	42.2702	-65.8741	4	
11	**25**	**09/04/2018**	**PS_02**	**RingNet**	**202**	**42.339**	**-65.8013**	**4**	Wire jumped the block and poor wire angle, so cancelled.
12	26	09/04/2018	PS_02	RingNet	202	42.3385	-65.8011	4	
13	28	09/04/2018	PS_01	RingNet	202	42.421	-65.7414	4	
14	30	09/04/2018	BBL_05	RingNet	202	42.1318	-65.5012	1	
15	32	09/04/2018	BBL_06	RingNet	202	42.0008	-65.51	1	
16	34	09/04/2018	BBL_07	RingNet	202	41.8671	-65.3509	1	
17	36	10/04/2018	PL_09	RingNet	202	42.381	-66.4034	4	
18	38	10/04/2018	PL_08	RingNet	202	42.4632	-66.8507	4	
19	40	10/04/2018	PL_07	RingNet	202	42.5541	-67.3028	4	
20	42	10/04/2018	PL_06	RingNet	202	42.6252	-67.754	4	
21	44	10/04/2018	PL_05	RingNet	202	42.7026	-68.2061	4	
22	46	10/04/2018	PL_04	RingNet	202	42.7896	-68.6562	4	

#	Event	Date	Station	Operation	Mesh Size (µm)	Slat (DD)	SLong (DD)	Objective	Comment
23	48	11/04/2018	YL_06	RingNet	202	43.3982	-68.6653	4	
24	50	11/04/2018	YL_07	RingNet	202	43.3292	-69.1056	4	
25	52	11/04/2018	PL_03	RingNet	202	42.876	-69.1077	4	
26	54	11/04/2018	PL_02	RingNet	202	42.9552	-69.5578	4	
27	56	11/04/2018	PL_01	RingNet	202	43.0314	-70.0015	4	
28	58	11/04/2018	YL_10	RingNet	202	43.1568	-70.2728	4	
29	60	11/04/2018	YL_09	RingNet	202	43.186	-70.0098	4	
30	62	11/04/2018	YL_08	RingNet	202	43.2581	-69.5568	4	
31	64	12/04/2018	YL_05	RingNet	202	43.4685	-68.2124	4	
32	66	12/04/2018	YL_04	RingNet	202	43.5376	-67.7509	4	
33	68	12/04/2018	YL_03	RingNet	202	43.6091	-67.303	4	
34	70	12/04/2018	YL_02	RingNet	202	43.6804	-66.8543	4	
35	72	12/04/2018	YL_01	RingNet	202	43.7506	-66.4009	4	
36	75	13/04/2018	HL_01	RingNet	202	44.4009	-63.4492	1	New net.
37	77	13/04/2018	HL_02	RingNet	202	44.2656	-63.3176	1	
38	78	13/04/2018	HL_02	RingNet	76	44.2666	-63.3157	1	
39	82	13/04/2018	HL_03	RingNet	202	43.8814	-62.8819	1	
40	83	13/04/2018	HL_03.3	RingNet	202	43.7583	-62.7489	1	
41	85	13/04/2018	HL_04	RingNet	202	43.4744	-62.4614	1	
42	87	13/04/2018	HL_05	RingNet	202	43.1803	-62.0989	1	
43	89	14/04/2018	HL_05.5	RingNet	202	42.9431	-61.8296	1	Paused upon descent and net was torn at recovery near mouth.
44	91	14/04/2018	HL_06	RingNet	202	42.8306	-61.732	1	New net deployed.
45	93	14/04/2018	HL_06.3	RingNet	202	42.7327	-61.6132	1	
46	**95**	**14/04/2018**	**HL_06.7**	**RingNet**	**202**	**42.617**	**-61.512**	**1**	Net lost – no sample recovered
47	97	14/04/2018	HL_07	RingNet	202	42.473	-61.4323	1	New net deployed
48	106	15/04/2018	HL_08	RingNet	202	42.3796	-61.302	2	

#	Event	Date	Station	Operation	Mesh Size (µm)	Slat (DD)	SLong (DD)	Objective	Comment
49	**108**	**15/04/2018**	**HL_09**	**RingNet**	**202**	**42.2336**	**-61.2095**	**2**	Cross bow slid down cable to schackle.
50	110	16/04/2018	HL_10	RingNet	202	42.0256	-61.055	2	
51	112	16/04/2018	HL_11	RingNet	202	41.7817	-60.9091	2	4 jars of jelly; Pyrosoma hanging from wire on block. Poor angle half way down, 30+. Bad again after 700 m.
52	**114**	**17/04/2018**	**SG_28**	**RingNet**	**202**	**43.7089**	**-59.0025**	**3**	Hit bottom so cast repeated.
53	115	17/04/2018	SG_28	RingNet	202	43.7085	-59.0069	3	
54	118	17/04/2018	GULD_03	RingNet	202	43.9999	-59.0202	3	
55	120	17/04/2018	GULD_04	RingNet	202	43.7887	-58.9016	3	
56	122	17/04/2018	SG_23	RingNet	202	43.8605	-58.7285	3	
57	123	17/04/2018	LL_07	RingNet	202	44.1337	-58.1793	1	
58	125	18/04/2018	LL_06	RingNet	202	44.4761	-58.5075	1	
59	127	18/04/2018	LL_05	RingNet	202	44.8157	-58.8512	1	
60	129	18/04/2018	LL_04	RingNet	202	45.1582	-59.1764	1	
61	131	18/04/2018	LL_03	RingNet	202	45.4923	-59.5188	1	
62	133	18/04/2018	LL_02	RingNet	202	45.6578	-59.7024	1	
63	135	18/04/2018	LL_01	RingNet	202	45.8251	-59.8503	1	
64	137	18/04/2018	STAB_01	RingNet	202	45.9999	-59.5328	10	
65	139	18/04/2018	STAB_02	RingNet	202	46.1086	-59.365	10	
66	141	18/04/2018	STAB_03	RingNet	202	46.2166	-59.1949	10	Ship taking roll on starboard side, can't find bottom.
67	143	19/04/2018	STAB_04	RingNet	202	46.3002	-59.064	10	Ship taking roll on starboard side, can't find bottom.
68	145	20/04/2018	CSL_01	RingNet	202	46.959	-60.2157	1	
69	147	20/04/2018	CSL_02	RingNet	202	47.0197	-60.1204	1	
70	150	20/04/2018	CSL_03	RingNet	202	47.0994	-59.9931	1	
71	152	20/04/2018	CSL_04	RingNet	202	47.2713	-59.7833	1	

#	Event	Date	Station	Operation	Mesh Size (µm)	Slat (DD)	SLong (DD)	Objective	Comment
72	154	21/04/2018	CSL_05	RingNet	202	47.4328	-59.5588	1	
73	156	21/04/2018	CSL_06	RingNet	202	47.5832	-59.3422	1	
74	158	21/04/2018	STAB_05	RingNet	202	46.4187	-58.8856	10	
75	160	22/04/2018	LL_08	RingNet	202	43.783	-57.8337	1	
76	162	22/04/2018	LL_09	RingNet	202	43.4735	-57.5276	1	
77	**164**	**23/04/2018**	**BP_00**	**RingNet**	**202**	**44.9995**	**-56.0279**	**11**	Hit bottom, cast had to be redone.
78	165	23/04/2018	BP_00	RingNet	202	45.0008	-56.027	11	
79	167	23/04/2018	BP_01	RingNet	202	44.9804	-56.1389	11	
80	169	23/04/2018	BP_04	RingNet	202	44.919	-56.4427	11	Flow meter not working?
81	171	23/04/2018	BP_05	RingNet	202	44.8892	-56.6313	11	Flow meter working.
82	173	23/04/2018	BANQ_B6	RingNet	202	44.8464	-56.8098	11	
83	175	23/04/2018	BANQ_B4	RingNet	202	44.7812	-57.2497	11	
84	177	23/04/2018	BANQ_B3	RingNet	202	44.7623	-57.3486	11	
85	179	23/04/2018	BANQ_B1	RingNet	202	44.7193	-57.6554	11	

Microbial Protein and Organic Micronutrient Sampling

Principle Investigator: Dr. Erin Bertrand (Dalhousie University, Department of Biology)
Sampling by: Magda Waclawik and [redacted] (Dalhousie University)

Objective

The objective was to collect rosette samples for protein and vitamin analyses in order to determine whether and how organic and organometallic micronutrients influence primary productivity and phytoplankton community structure on the Scotian Shelf. Sampling locations were coordinated with the LaRoche lab since our datatypes are synergistically informative.

Microbial Protein Sampling

Purpose

Proteins are key to microbial activity: the type and amount of proteins present determines, in large part, the contributions microbes make to the ecosystems they occupy. Proteins can also be used as indices for nutritional status: elevated expression of specific proteins can be diagnostic for different nutritional states, such as nitrogen starvation, iron starvation, or vitamin starvation. Protein sequences also contain taxonomic information and can be used to assess contributions of different organisms to specific functions.

Samples were collected for targeted, mass spectrometry- based proteomic analyses of microbial communities in order to characterize the role of organic micronutrients in structuring phytoplankton communities on the Scotian Shelf. Primary objectives include measuring phytoplankton nutritional status indicator proteins (nitrogen, vitamin B_{12}, vitamin B_1 starvation) and vitamin- production biomarker proteins. Development and application of peptides for primary producer community composition analyses is a secondary focus.

Sampling Methods

10L samples: A total of 71 size-fractionated microbial protein samples (10L of water each) were taken from the CTD rosette at depths ranging from the surface to 250 m (Table 11) along the lines of the AZMP located in Canadian waters. Water was filtered sequentially through 3 and 0.2 µm polycarbonate filters via peristaltic pumping. Filters were then frozen immediately at -80°C.

Vitamin Sampling

Purpose

To determine the particulate and dissolved concentrations of organic and organometallic micronutrients on the Scotian Shelf. Organic and organometallic micronutrients are required by many phytoplankton groups and only produced by a select few microbes,

setting up a series of interactive dependencies between microbial groups. The importance of these dependencies are not well known, as they have not yet been studied on the Scotian Shelf. Measuring the concentrations of these micronutrients in the particulate and dissolved phases is one step towards understanding the role of microbial interactions in driving primary productivity and phytoplankton community structure.

Sampling Methods

A total of 71 particulate and 31 dissolved vitamin samples (1L each) were taken from the CTD rosette at depths ranging from the surface to 250m depth along lines of the AZMP in Canadian waters (Table 11). Samples were protected from light and gently vacuum filtered through 0.2 µm nylon filters. Filters were frozen at -80°C and dissolved samples were frozen in amber HDPE bottles at -20°C.

Table 11. Protein and vitamin samples – Bertrand lab – AZMP Spring 2018 – HUD2018004.

Station	Event #	Depth (m)	Sample ID	Protein 0.2um	Protein 3um	Particulate Vitamin	Dissolved Vitamin
BBL1	5	1	445581	1	1	1	-
		40	445574	1	1	1	-
BBL3	9	1	445609	1	1	1	-
		20	445603	1	1	1	-
		40	445600	1	1	1	-
		80	445595	1	1	1	-
BBL5	31	1	445760	1	1	1	-
		20	445755	1	1	1	-
		40	445751	1	1	1	-
		80	445746	1	1	1	-
BBL7	35	1	445800	1	1	1	-
		20	445796	1	1	1	-
		80	445789	1	1	1	-
		250	445784	1	1	1	-
HL02	79	1	446032	1	1	1	1
		20	446028	1	1	1	1
		40	446024	1	1	1	1
		80	446018	1	1	1	1
HL04	86	1	446073	1	1	1	1
		20	446068	1	1	1	1
		40	446064	1	1	1	1
		60	446060	1	1	1	1
HL06	92	1	446117	1	1	1	1

Station	Event #	Depth (m)	Sample ID	Protein 0.2um	Protein 3um	Particulate Vitamin	Dissolved Vitamin
		20	446113	1	1	1	1
		50	446108	1	1	1	1
		80	446104	1	1	1	1
HL07	105	1	446178	1	1	1	1
		20	446174	1	1	1	1
		50	446170	1	1	1	1
GULD04	121	1	446323	1	1	1	-
		20	446319	1	1	1	-
		60	446315	1	1	1	-
		250	446311	1	1	1	-
LL7	124	1	446347	1	1	1	1
		20	446342	1	1	1	1
		80	446335	1	1	1	1
		250	446330	1	1	1	1
LL4	130	1	446383	1	1	1	1
		20	446379	1	1	1	1
		40	446375	1	1	1	1
		80	446369	1	1	1	1
LL1	136	1	446423	1	1	1	1
		20	446419	1	-	1	1
		40	446415	1	-	1	1
		60	446411	1	1	1	1
STAB01	138	1	446435	-	-	-	-
		40	446429	-	-	-	-
CSL01	146	1	446485	1	1	1	-
		20	446479	1	1	1	-
		40	446473	1	1	1	-
		60	446469	1	1	1	-
CSL04	153	1	446534	1	1	1	-
		20	446528	1	1	1	-
		60	446522	1	1	1	-
		300	446514	1	1	1	-
STAB05	159	1	446583	1	1	1	-
		20	446579	1	1	1	-
		80	446571	1	1	1	-
		300	446565	1	1	1	-
LL9	163	1	446625	1	1	1	1

Station	Event #	Depth (m)	Sample ID	Protein 0.2um	Protein 3um	Particulate Vitamin	Dissolved Vitamin
		20	446621	1	1	1	1
		80	446613	1	1	1	1
		250	446609	1	1	1	1
BANQ_B6	174	1	446689	1	1	1	-
		20	446683	1	1	1	-
		80	446677	-	1	1	-
		250	446671	-	1	1	-
BANQ_B4	176	1	446709	1	1	1	-
		20	446703	1	1	1	-
		40	446699	1	1	1	-
		80	446695	1	1	1	-
BANQ_B1	180	1	446727	1	1	1	-
		20	446721	1	1	1	-

Microbial Community Analysis

Principle Investigator: Dr. Julie LaRoche (Dalhousie University)
Sampling by: Magda Waclawik and [redacted] (Dalhousie University)

Purpose

Microbial communities and their associated processes are the foundation of marine life. Of particular interest to our group is the marine nitrogen cycle, comprising complex microbially-driven reactions whereby atmospheric nitrogen is fixed into a biologically-available form and cycled through the ecosystem. Though nitrogen is an essential element for life, the availability of fixed nitrogen can be a limiting factor for primary production and thus diazotrophs – organisms capable of biological nitrogen fixation – can be key to the productivity of an ecosystem.

Samples were collected for genomic and fluorescence-based analyses of the microbial communities on the Scotian shelf. Community composition will be assessed via 16S (bacterial) & 18S (eukaryotic) tag sequencing, and the naturally-fluorescent population will be characterized via flow cytometry. The latter method can also be used to quantify the bacterial community via nucleic acid stain SYBR green. Community function will be assessed via metagenomic sequencing, and qPCR assays for selected functional genes. Further samples were taken for manipulation in the lab, including targeted metagenomics and single cell isolation via fluorescence-associated cell sorting (FACS), and enrichment culturing of putative diazotrophs.

Sampling Methods

Genomics:
At 19 select stations along the lines of the AZMP located in Canadian waters, duplicate 4L water samples were collected from the CTD rosette at each of 4 depths ranging from the surface to 300m (Table 12); at 3 additional stations, only 2 depths were collected, for a total of 81 samples (Table 12). Each water sample was sequentially filtered through 3 and 0.2µm polycarbonate filters by peristaltic pump until the water was depleted or the filters clogged. Filters were immediately frozen at -80°C.

Flow Cytometry:
At each station and depth where genomic samples were collected, duplicate 2mL water samples were fixed with 2% paraformaldehyde (PFA) for 10 minutes at room temperature, then frozen at -80°C for later enumeration of bacteria and characterization of the naturally fluorescent microbial community via the Accuri C6 flow cytometer.

At select stations (Table 12), 45mL of water were mixed with 5mL of gly-TE buffer and frozen at -80°C for later cell sorting on the BD Influx FACS instrument.

Enrichment Cultures:
At select stations (Table 12), 500mL water samples were collected. These samples were spiked with phosphate (200nM) and iron (2nM) and secured to the window of the lab to approximate natural light/dark cycles and ambient temperature until return to the lab.

Table 12. Microbial community samples – LaRoche lab – AZMP Spring 2018 – HUD2018004.

Station	Event #	Depth (m)	Sample ID	DNA samples (size-fractionated)	Standard Flow cytometry	Sorting Flow Cytometry	500 mL culture
BBL1	5	1	445580	2	2	-	-
		40	445573	2	2	-	-
BBL3	9	1	445608	2	2	-	-
		20	445604	2	2	-	-
		40	445599	2	2	-	-
		80	445594	2	2	-	-
BBL5	31	1	445759	2	2	1	1
		20	445754	2	2	-	-
		40	445750	2	2	-	-
		80	445745	2	2	1	1
BBL7	35	1	445799	2	2	1	1
		20	445795	2	2	-	-
		80	445788	2	2	1	1
		250	445783	2	2	-	-
HL02	79	1	446033	2	2	-	-
		20	446027	2	2	1	1
		40	446023	2	2	-	-
		80	446019	2	2	-	-
HL04	86	1	446072	2	2	-	-
		20	446067	2	2	-	-
		40	446063	2	2	-	-
		60	446059	2	2	-	-
HL06	92	1	446118	2	2	1	1
		20	446114	2	2	-	-
		50	446109	2	2	1	1
		80	446105	2	2	-	-
HL07	105	1	446179	2	2	-	-
		20	446173	2	2	-	-
		50	446169	2	2	-	-
		80	446167	2	2	-	-
HL08	107	1	446203	2	2	1	1
		20	446200	2	2	-	-

Station	Event #	Depth (m)	Sample ID	DNA samples (size-fractionated)	Standard Flow cytometry	Sorting Flow Cytometry	500 mL culture
		100	446193	2	2	-	-
		250	446191	2	2	-	-
HL11	113	1	446274	0	0	-	-
		20	446272	2	2	-	-
		100	446266	2	2	-	-
		250	446265	2	2	-	-
GULD04	121	1	446234	2	2	-	-
		20	446318	2	2	-	-
		60	446312	2	2	1	1
		250	446306	2	2	-	-
LL7	124	1	446346	2	2	-	-
		20	446341	2	2	-	-
		80	446334	2	2	-	-
		250	446329	2	2	-	-
LL4	130	1	446384	2	2	-	-
		20	446378	2	2	-	-
		40	446374	2	2	-	-
		80	446370	2	2	-	-
LL1	136	1	446424	2	2	-	-
		20	446418	2	2	-	-
		40	446414	2	2	-	-
		60	446410	2	2	-	-
STAB01	138	1	446346	2	2	-	-
		40	446248	2	2	-	-
CSL01	146	1	446484	2	2	-	-
		20	446478	2	2	-	-
		40	446474	2	2	-	-
		60	446468	2	2	-	-
CSL04	153	1	446533	2	2	-	-
		20	446529	2	2	-	-
		60	446523	2	2	-	-
		300	446515	2	2	-	-
STAB05	159	1	446584	2	2	-	-
		20	446578	2	2	-	-
		80	446572	2	2	-	-
		300	446566	2	2	-	-
LL9	163	1	446624	2	2	-	-
		20	446620	2	2	-	-

Station	Event #	Depth (m)	Sample ID	DNA samples (size-fractionated)	Standard Flow cytometry	Sorting Flow Cytometry	500 mL culture
		80	446614	2	2	-	-
		250	446610	2	2	-	-
BANQ_B6	174	1	446688	2	2	-	-
		20	446684	2	2	-	-
		80	446676	1	2	-	-
		250	446672	2	2	-	-
BANQ_B4	176	1	446708	2	2	-	-
		20	446704	2	2	-	-
		40	446700	2	2	-	-
		80	446694	2	2	-	-
BANQ_B1	180	1	446726	2	2	-	-
		20	446722	2	2	-	-

Pelagic Seabird and Marine Mammal Observations

Seabird Survey Report
7-24 April 2018
Canadian Wildlife Service, Environment and Climate Change Canada
Prepared by: Carina Gjerdrum carina.gjerdrum@ec.gc.ca
Observer(s): Jeannine Winkel

Background

The east coast of Canada supports millions of breeding marine birds as well as migrants from the southern hemisphere and northeastern Atlantic. In 2005, the Canadian Wildlife Service (CWS) of Environment Canada initiated the Eastern Canada Seabirds at Sea (ECSAS) program with the goal of identifying and minimizing the impacts of human activities on birds in the marine environment. Since that time, a scientifically rigorous protocol for collecting data at sea and a sophisticated geodatabase have been developed, relationships with industry and DFO to support offshore seabird observers have been established, and over 100,000 km of ocean track have been surveyed by CWS-trained observers. These data are now being used to identify and address threats to birds in their marine environment. In addition, data are collected on marine mammals, sea turtles, sharks, and other marine organisms when they are encountered.

Methods

Seabird surveys were conducted from the port side of the bridge of the CCG Hudson during the Scotian Shelf AZMP from 7-24 April 2018. Surveys were conducted while the ship was moving at speeds greater than 4 knots, looking forward and scanning a 90° arc to one side of the ship. All birds observed on the water within a 300m-wide transect were recorded, and we used the snapshot approach for flying birds (intermittent sampling based on the speed of the ship) to avoid overestimating abundance of birds flying in and out of transect. Distance sampling methods were incorporated to address the variation in bird detectability. Marine mammal and other marine wildlife observations were also recorded, although surveys were not specifically designed to detect marine mammals. Details of the methods used can be found in the CWS standardized protocol for pelagic seabird surveys from moving platforms[1].

[1]Gjerdrum, C., D.A. Fifield, and S.I. Wilhelm. 2012. Eastern Canada Seabirds at Sea (ECSAS) standardized protocol for pelagic seabird surveys from moving and stationary platforms. Canadian Wildlife Service Technical Report Series. No. 515. Atlantic Region. vi + 36 pp.

Results

Seabird Sightings

We surveyed 1854 km of ocean from 7-24 April 2018. A total of 1785 birds were observed in transect (2731 birds in total) from 11 families (Table 13). Bird densities averaged 3.1 birds/km^2 (ranging from 0 – 183.8 birds/km^2). The highest densities of birds (> 50 birds/km^2) were observed in primarily in the eastern part of the survey area, in Sydney Harbour, Misaine Bank, the mouth of the Laurentian Channel, northern Banquereau and slope waters beyond the Haldimand Canyon, but also in far western survey area in the Gulf of Maine (Figure 30).

Dovekie comprised of 15% of the birds sighted (Table 13). The Scotian Shelf (and Grand Banks of NL) are important wintering grounds for Dovekie breeding in Greenland. The bulk of the Dovekies observed on this survey were in slope waters off Banquereau (Figure 31a), likely heading back to their breeding grounds. Common Murres were also encountered relatively frequently, accounting for 4% of the sightings (Table 13), and were observed in the highest densities on Misaine Bank (Figure 31b). Together, the alcids made up a total of 26% of the birds observed.

Herring Gulls accounted for 9% of the sightings (Table 13), and were observed in the highest densities on Banquereau (Figure 31c). Great Black-backed Gulls were less numerous, but similarly distributed. Both these species breed in Nova Scotia. Together the gull species accounted for 15% of the birds sighted.

Northern Gannets were sighted throughout the survey area, but in the highest densities around SW Nova Scotia in more inshore waters (Figure 31d). Northern Gannets breed in NL and the Gulf of St. Lawrence and are common on the Scotian Shelf this time of year as they make their way back their breeding colonies from the Gulf of Mexico and areas along the eastern seaboard of the US.

Marine Mammal Sightings

A total of 134 marine mammals were recorded during the surveys (Table 14), 46% of which were humpback whales, primarily observed in the eastern sections of the survey (Figure 32a). A single pod of 20 white-beaked dolphins were observed on Misaine Bank (Figure 32b).

Gully MPA

Surveys were conducted within the Gully MPA on 17 April. A total of 46 birds were observed, most of which were Dovekie (85%), but no marine mammals were observed in this area (Table 15; Figure 32c).

St. Anns Bank MPA

Surveys were conducted within the St. Anns Bank MPA on 18 April and then again on 21 April. Just 19 birds and 3 unidentified cetacean species were observed during the transits (Table 16; Figure 32d).

Table 13. List of bird species observed during surveys on the Scotian Shelf AZMP, from 7-24 April, 2018.

Family	English	Latin	Number observed in transect	Total number observed
Gaviidae	Common Loon	*Gavia immer*	5	5
Procellariidae	Northern Fulmar	*Fulmarus glacialis*	73	97
	Sooty Shearwater	*Ardenna griseus*	12	19
	Manx Shearwater	*Puffinus puffinus*	1	3
Hydrobatidae	Leach's Storm-Petrel	*Oceanodroma leucorhoa*	50	50
	Wilson's Storm Petrel	*Oceanites oceanicus*	0	1
	Unidentified Storm-Petrels	Hydrobatidae	0	4
Phalacrocoracidae	Double-crested Cormorant	*Phalacrocorax auritus*	25	33
Sulidae	Northern Gannet	*Morus bassanus*	249	422
Anatidae	Canada Goose	*Branta canadensis*	0	2
	Surf Scoter	*Melanitta perspicillata*	57	61
	Black Scoter	*Melanitta nigra*	6	6
	White-winged Scoter	*Melanitta fusca*	2	11
	Unidentified Scoters	*Melanitta*	17	43
	Common Eider	*Somateria mollissima*	49	93
	Long-tailed Duck	*Clangula hyemalis*	0	5
	Unidentified Ducks	All duck genera	14	20
Laridae	Pomarine Jaeger	*Stercorarius pomarinus*	1	1
	Unidentified Jaegers	*Stercorarius* Jaegers	0	1
	Black-legged Kittiwake	*Rissa tridactyla*	49	59
	Herring Gull	*Larus argentatus*	274	355
	Great Black-backed Gull	*Larus marinus*	119	155
	Lesser Black-backed Gull	*Larus fuscus*	1	1
	Glaucous Gull	*Larus hyperboreus*	5	8
	Iceland Gull	*Larus glaucoides*	3	3
	Unidentified Gull	*Larus*	1	140
Alcidae	Dovekie	*Alle alle*	458	619
	Common Murre	*Uria algaa*	115	118
	Thick-billed Murre	*Uria lomvia*	13	19
	Unidentified Murre	*Uria*	94	212
	Black Guillemot	*Cepphus grylle*	14	19
	Razorbill	*Alca torda*	10	14
	Atlantic Puffin	*Fratercula arctica*	8	10
	Unidentified Alcid	Alcidae	51	102
Picidae	Northern Flicker	*Colaptes auratus*	1	1
Turtidae	American Crow	*Corvus brachyrhynchos*	0	1
Emberizidae	Song Sparrow	*Melospiza melodia*	3	5
	Savannah Sparrow	*Passerculus sandwichensis*	2	2
	Fox Sparrow	*Passerella iliaca*	1	1
	Dark-eyed Junco	*Junco hyemalis*	2	10
Total			**1785**	**2731**

Table 14. List of marine mammals, fish and invertebrates observed during surveys on the Scotian Shelf AZMP, from 7-24 April, 2018.

English	Latin	Total number observed
Humpback Whale	*Megaptera novaeangliae*	62
Long-finned Pilot Whale	*Globicephala melas*	7
Fin Whale	*Balaenoptera physalus*	1
Minke Whale	*Balaenoptera acutorostrata*	1
White-beaked Dolphin	*Lagenorhynchus albirostris*	20
Common Dolphin	*Delphinus delphis*	3
Harbour Porpoise	*Phocoena phocoena*	1
Unidentified Dolphins	Delphinidae	21
Unidentified Whales and Dolphins	Cetacea	13
Gray Seal	*Halichoerus grypus*	2
Harbour Seal	*Phoca vitulina*	1
Harp Seal	*Pagophilus groenlandicus*	1
Unidentified Seals	Phocidae	1
Ocean Sunfish	*Mola mola*	1
Portuguese Man-Of-War	*Physalia physalia*	1
Total		**136**

Table 15. List of species observed in the Gully Marine Protected Area during surveys on the Scotian Shelf AZMP on 17 April, 2018.

English	Total number observed
Dovekie	39
Herring Gull	2
Northern Gannet	1
Northern Fulmar	1
Pomarine Jaeger	1
Atlantic Puffin	1
Leach's Storm-petrel	1
Total	**46**

Table 16. List of species observed in the St. Anns Bank Marine Protected Area during surveys on the Scotian Shelf AZMP, on 18 and 21 April, 2018.

English	Total number observed
Northern Gannet	8
Northern Fulmar	6
Herring Gull	3
Black-legged Kittiwake	1
Common Murre	1
Unidentified cetacean	3
Total	**22**

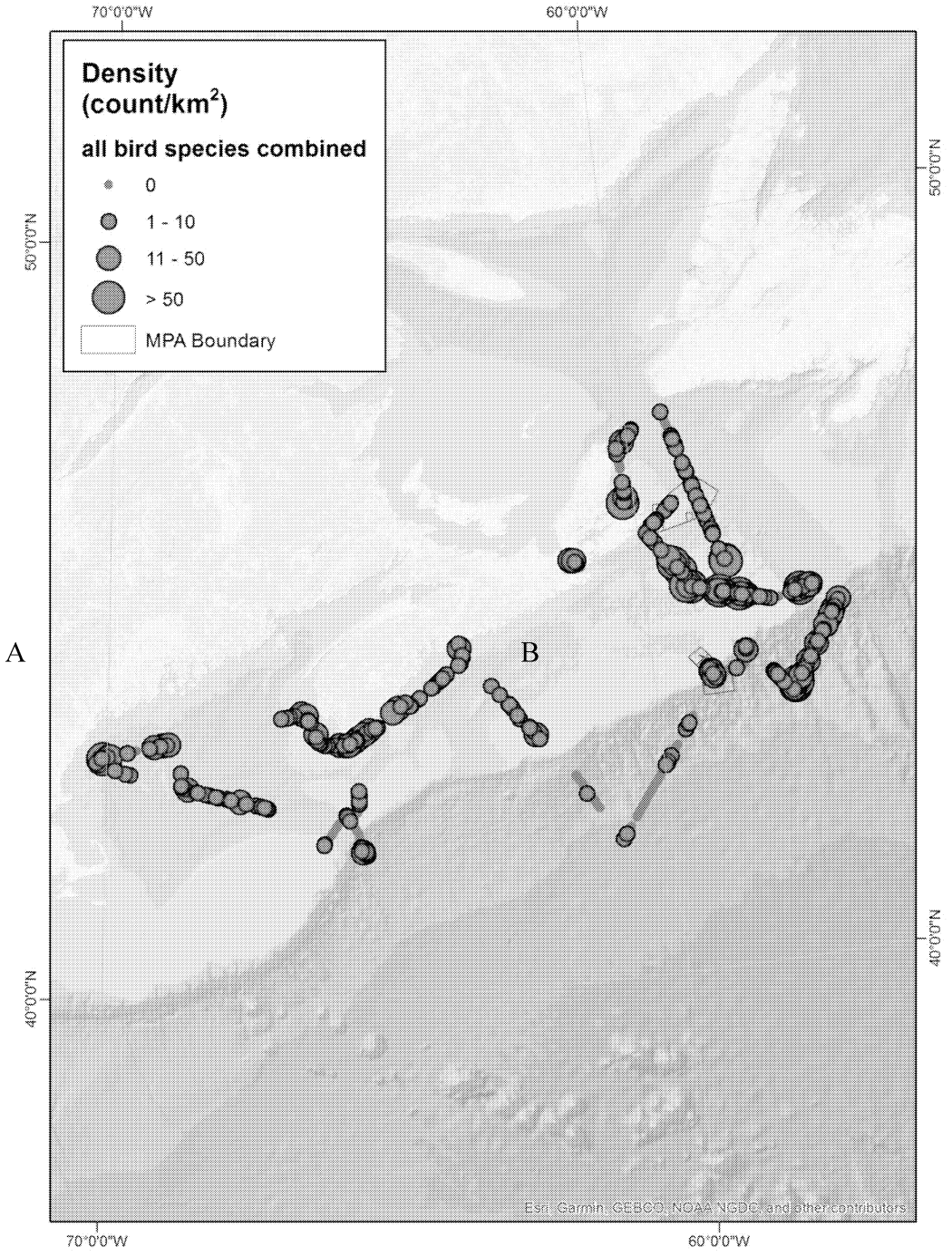


Figure 30. Density of birds observed during the seabird survey on the Scotian Shelf AZMP, from 7-24 April 2018.

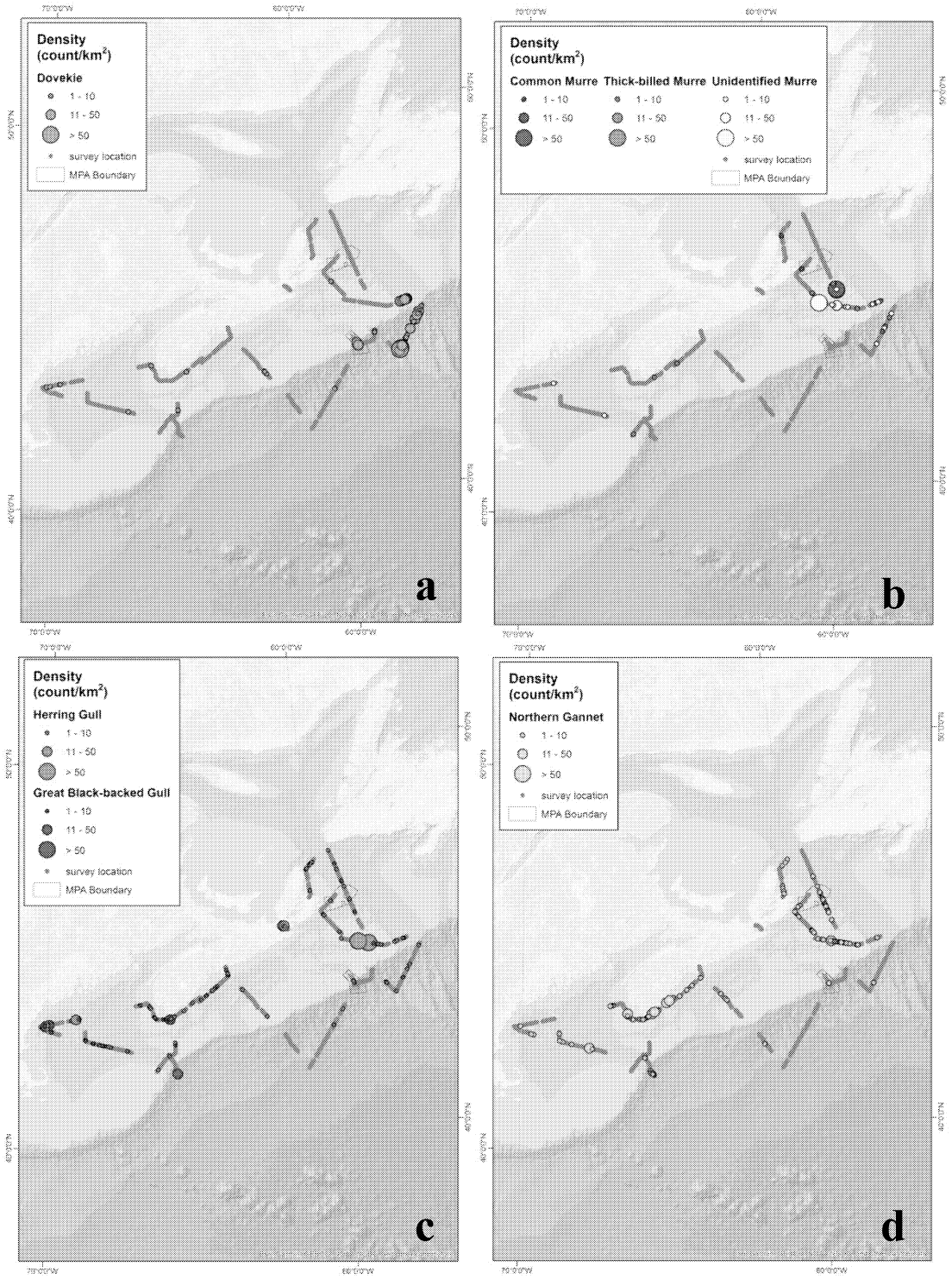


Figure 31. Density of a) Dovekies, b) Murres, c) Herring and Black-backed Gulls, and d) Northern Gannets observed during the seabird survey on the Scotian Shelf AZMP, from 7-24 April 2018.

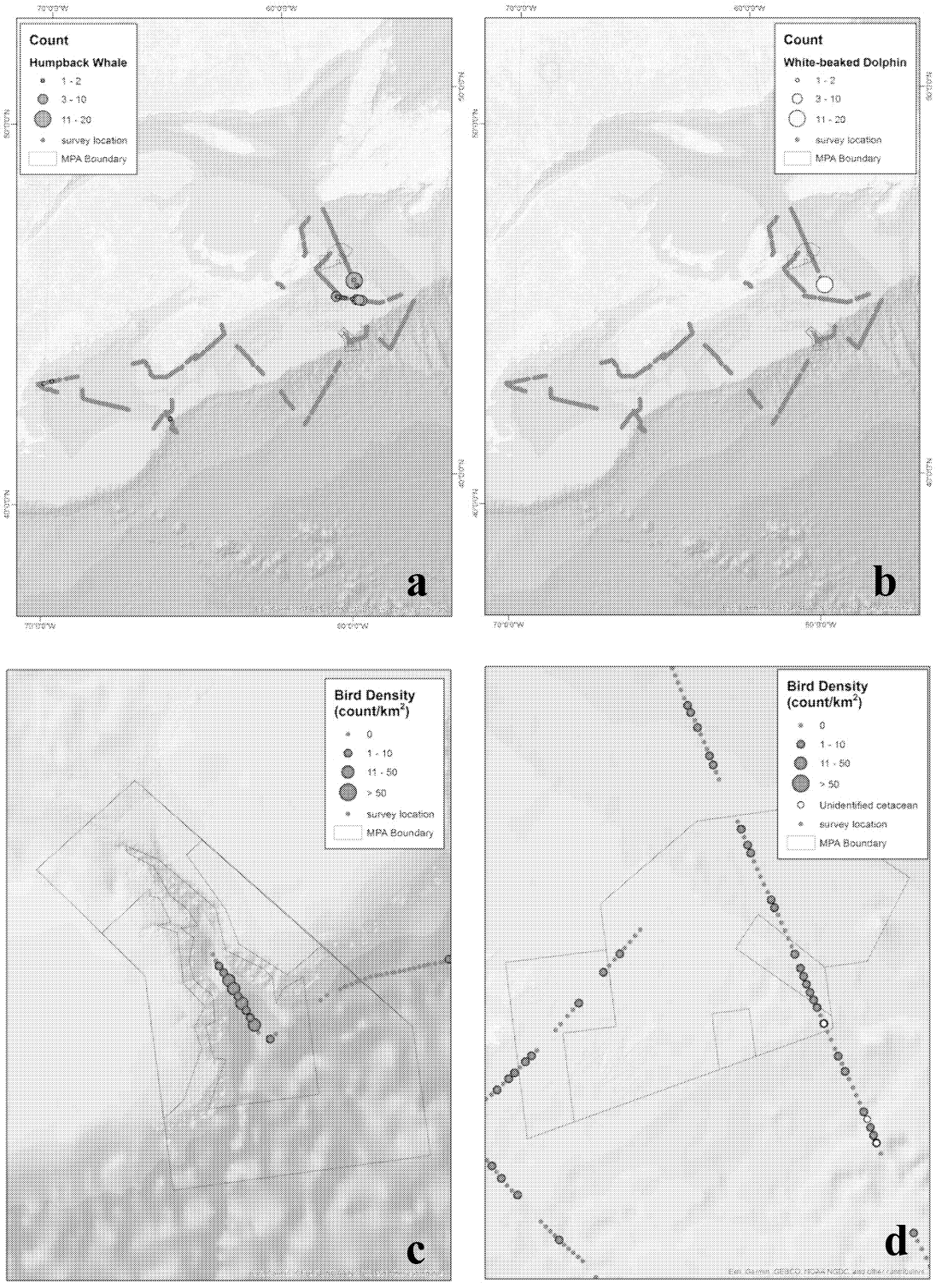


Figure 32. Counts of a) humpback whales and b) white-beaked dolphins during survey from 7-24 April 2018; and sightings in c) the Gully Marine Protected Area on 17 April 2018, and d) the St Anns Bank MPA on 18 and 21 April 2018.

Underway Sampling

Contributions by: Adam Hartling
Division: OESD

Navigation and Bathymetry

The science navigation system on the Hudson consists of both Novatel ProPak6 and Applanix PosMV systems. The Novatel is a two antenna receiver that provides both position and heading data. The PosMV includes an IMU and provides both position and attitude data. The NMEA output from both systems is logged by the GSC Navnet software. The output from one of the receivers can be selected to be added to the multiplexed serial data stream available throughout the ship. The output from this selected receiver is also logged by the Scientific Computing System along with the TSG data. The output rate for both receivers is 1 Hz.

The dual frequency Knudsen sounder was used for determining the water depth. The 3.5kHz channel was used exclusively for depth sounding during the cruise. During CTD stations the Raytheon PTR/LSR sounder located in the winch-room was used for depth sounding and monitoring the distance from bottom of a 12kHz pinger mounted on the CTD package. The offset for the ram is 6m when retracted and 8m when extended. Both 12kHz transducers are mounted on the ram. One 12kHz transducer on the ram was used for tracking the pinger, the other has failed and must be replaced in the next dry-docking.

Underway Seawater System – Thermosalinograph

An underway system, also referred to as thermosalinograph (TSG), was placed in the forward lab and was connected to the pumped uncontaminated seawater plumbing. The configuration on HUD2018004 consisted of an SBE21 with conductivity (sn: 3396) and temperature (sn: 3396), an external temperature located at the ship's intake (SBE 38 sn: 0766), WET Labs chlorophyll WETStar (sn: WSCHL-1468) with a scale factor of 15.5 ug/l/V, Seapoint CDOM fluorometer (sn: 6211) with a 50x gain jumper and SBE pH sensor (sn: 1214). The sampling rate was 0.2 Hz.

The pump was turned on in Bedford Basin at ~0800 LT on April 6th, just prior to departure. The water pumped to the forward lab with exhaust routes (direct discharge over the side of the ship), through the TSG and from the de-bubbler. The flow rate remained fairly constant throughout the mission at an average flow rate of ~44 l/min. The system remained running until ~0900 on the 19th of April when we arrived in Sydney for repairs. The system was re-started on the 20th at ~0900 in Sydney Harbour as we resumed operations. The system was finally turned off on April 24th at ~0700 as we began our final approach to Mulgrave, N.S. for crew change.

Over the duration of the cruise a single PCO2 and TIC sample, along with 2 Chla samples were acquired every day and provided with a unique sample ID. The scanned paper log for these samples should be located here:

\\dcnsbiona01a\BIODataSvcSrc\2010s\2018\HUD2018004\SCANNED_LOGS and the digital e-logs can be found here: \\dcnsbiona01a\BIODataSvcSrc\2010s\2018\HUD2018004\ELOG\Logbooks\Flow-Through Log. There were a total of 15 PCO2, 15 TIC and 30 Chla samples taken from April 6 – April 24.

TSG underway data was managed the NOAA Scientific Computing Systems (SCS) software. These data are submitted to ODIS upon conclusion of the mission but Dr. Dave Hebert (Dave.Hebert@dfo-mpo.gc.ca) is the point of contact for these data.

Data Management

Prepared by: Robert Benjamin
Division: Program Coordination and Support

Data Collection

In addition to standard AZMP manual data collection methods (i.e., Bridge log, various equipment specific deck sheets) ELOG, an electronic logbook system for collecting event metadata including position and sounding, was again used during HUD2018004. This electronic logbook was accessible via computers connected to the *science network* on-board the vessel with one available at each major work area. Metadata related to each piece of equipment was collected in the electronic log including position/time deployed, on bottom and recovered. Additional logbooks were employed to act as an itinerary, a daily operational log and a logbook to monitor the flow through system in the forward lab. All digital logbooks were backed up hourly and at the end of the Mission and were sent to ODIS for storage.

Nav-Net, an on board ship's data collection system was used to collect all streaming data available during the entire mission with the exception of the Flow-through. These data include GPS data, sounder data, gyro data, wind and motion data. These data will be located in the NavNet archive here: \\dcnsbiona01a\BIODataSvcSrc\Navnet

Data Input Template

Reports were generated from shipboard input data in the AZMP Template Database to compare with corresponding CTD sensor data and conduct preliminary analyses included in this report.

GIS

Daily navigation and operations were maintained in a graphical information system (QGIS). Final line and point shapefile were generated from these data for the cruise report.

Hardware

Regulus/Aldebaran computers (supplied by NRCAN) were placed in the Drawing room, the CTD computer room, the Forward lab and the general purpose lab (GP Lab) to provide positioning and station name information to operations in these locations.

Systems Development Project

There was some discussion on board the ship for streamlining the ship-board methods for data collection and from subsequent shore-side analyses. The emphasis over the past 4 years has been to improve the quality of ship-board and shore-side data and meta-data management. Various systems and controls have been employed as immediate stop-gaps (ELOG; AZMP database template; standardized QC; improved data submission guidelines; improved archival folder structures; developing and improving feedback mechanisms; audits, repairs or existing databases; creation of new databases; etc…). These efforts are well underway and in some cases complete or near completion, and they have dramatically improved the quality, accuracy and comprehensiveness of the data submitted by AZMP. These systems have dramatically improved our efficiency while also decreasing errors so researchers can use these data with confidence. Nonetheless, more effort should be placed on improving efficiencies and modernizing outdated systems and data management approaches. The AZMP Steering Committee and ODIS will work together to create a plan to modernize our data collection and management over the coming years.

Already systems are being explored to help with sample tracking, water budget planning and improved data entry for at sea laboratory analysis. The development of a data entry system for Chlorophyll that has been analysed at sea is well underway. The Chlorophyll Input System includes well known and accepted formulas used to convert meter readings into valid Chlorophyll A and Phaeophytin values eliminating the need to use and modify Excel formulas when system calibrations or new Blanks need to be incorporated. The new Lab system will also inventory and manage all fluorometers and there calibrations.

APPENDICES

Appendix 1. CTD Configuration Files

Appendix 1a. HUD2018004.xmlcon (Event 1)

Date: 04/04/2018

Instrument configuration file:
Z:\CurrentlyDeployed\Shipboard_Environment\CRUISE_SETUPS\HUD2018004\CTD_Acquisition\2018004HUD\ctd_con\HUD2018004.xmlcon

Configuration report for SBE 911plus/917plus CTD

Frequency channels suppressed : 0
Voltage words suppressed : 0
Computer interface : RS-232C
Deck unit : SBE11plus Firmware Version >= 5.0
Scans to average : 1
NMEA position data added : Yes
NMEA depth data added : No
NMEA time added : No
NMEA device connected to : deck unit
Surface PAR voltage added : Yes
Scan time added : No

1) Frequency 0, Temperature

Serial number : 5083
Calibrated on : 02-Dec-17
A : 3.68121240e-003
B : 5.97265115e-004
C : 1.50057603e-005
D : 1.97182834e-006
F0 : 2984.722
Slope : 1.00000000
Offset : 0.0000

2) Frequency 1, Conductivity

Serial number : 3562
Calibrated on : 07-Dec-17
G : -9.84211899e+000
H : 1.20149777e+000
I : -1.12798269e-003

J : 1.33106553e-004
CTcor : 3.2500e-006
CPcor : -9.57000000e-008
Slope : 1.00000000
Offset : 0.00000

3) Frequency 2, Pressure, Digiquartz with TC

Serial number : 1214
Calibrated on : 30-Nov-16
C1 : -4.470905e+004
C2 : 3.840789e-001
C3 : 1.367850e-002
D1 : 3.661600e-002
D2 : 0.000000e+000
T1 : 3.015271e+001
T2 : -1.367200e-004
T3 : 3.926620e-006
T4 : 3.761680e-009
T5 : 0.000000e+000
Slope : 0.99999865
Offset : -1.26180
AD590M : 1.280000e-002
AD590B : -9.348400e+000

4) Frequency 3, Temperature, 2

Serial number : 1376
Calibrated on : 08-Dec-17
A : 3.68121183e-003
B : 6.00661106e-004
C : 1.51504431e-005
D : 2.12620555e-006
F0 : 6469.435
Slope : 1.00000000
Offset : 0.0000

5) Frequency 4, Conductivity, 2

Serial number : 1076
Calibrated on : 06-Dec-17
G : -4.18969113e+000
H : 5.65236010e-001
I : 3.29574520e-004
J : 1.37368013e-005
CTcor : 3.2500e-006
CPcor : -9.57000000e-008
Slope : 1.00000000

Offset : 0.00000

6) A/D voltage 0, Altimeter

Serial number : 59017
Calibrated on : 01-Mar-2017
Scale factor : 15.000
Offset : 0.000

7) A/D voltage 1, PAR/Logarithmic, Satlantic

Serial number : 1043
Calibrated on : 01-Dec-2015
a0 : 1.03324700
a1 : 0.80736900
Im : 1.35890000
Multiplier : 1.00000000

8) A/D voltage 2, Oxygen, SBE 43

Serial number : 0133
Calibrated on : 01-Dec-2017
Equation : Sea-Bird
Soc : 4.04880e-001
Offset : -6.32800e-001
A : -3.54420e-003
B : 1.53460e-004
C : -2.54240e-006
E : 3.60000e-002
Tau20 : 1.01000e+000
D1 : 1.92634e-004
D2 : -4.64803e-002
H1 : -3.30000e-002
H2 : 5.00000e+003
H3 : 1.45000e+003

9) A/D voltage 3, Oxygen, SBE 43, 2

Serial number : 0042
Calibrated on : 19-Dec-2017
Equation : Sea-Bird
Soc : 4.34300e-001
Offset : -4.93300e-001
A : -3.30140e-003
B : 1.49820e-004
C : -1.91610e-006
E : 3.60000e-002
Tau20 : 1.47000e+000

D1 : 1.92634e-004
D2 : -4.64803e-002
H1 : -3.30000e-002
H2 : 5.00000e+003
H3 : 1.45000e+003

10) A/D voltage 4, Fluorometer, Seapoint Ultraviolet

Serial number : 3668
Calibrated on : 1-Jan-2015
Range : 50.000000
Offset : 0.000000

11) A/D voltage 5, Fluorometer, Seapoint

Serial number : 6210
Calibrated on : 1-Jan-2015
Gain setting : 3 x, 0-50 µg/l
Offset : 0.000

12) A/D voltage 6, pH

Serial number : 1129
Calibrated on : 12-Feb-2018
pH slope : 4.6510
pH offset : 2.5163

13) A/D voltage 7, OBS, WET Labs, ECO-BB

Serial number : 1490
Calibrated on : 9-Aug-2016
ScaleFactor : 0.002983
Dark output : 0.048000

14) SPAR voltage, Unavailable

15) SPAR voltage, SPAR/Surface Irradiance

Serial number : 1069
Calibrated on : 24-Jun-2016
Conversion factor : 1.00000000
Ratio multiplier : 1.00000000

Scan length : 40

Appendix 1b. HUD2018004C.xmlcon (Events 2-35)

Date: 04/30/2018

Instrument configuration file:
C:\Users\CogswellA\Documents\AZMP\Missions\2018\2018 Spring\at sea\2018_HUD2018004\CTD\CTD_ACQUISITION\2018004HUD\ctd_con\HUD20180 04C.xmlcon *

Configuration report for SBE 911plus/917plus CTD

Frequency channels suppressed : 0
Voltage words suppressed : 0
Computer interface : RS-232C
Deck unit : SBE11plus Firmware Version >= 5.0
Scans to average : 1
NMEA position data added : Yes
NMEA depth data added : No
NMEA time added : No
NMEA device connected to : deck unit
Surface PAR voltage added : Yes
Scan time added : No

1) Frequency 0, Temperature

Serial number : 5083
Calibrated on : 02-Dec-17
A : 3.68121240e-003
B : 5.97265115e-004
C : 1.50057603e-005
D : 1.97182834e-006
F0 : 2984.722
Slope : 1.00000000
Offset : 0.0000

2) Frequency 1, Conductivity

Serial number : 3562
Calibrated on : 07-Dec-17
G : -9.84211899e+000
H : 1.20149777e+000
I : -1.12798269e-003
J : 1.33106553e-004
CTcor : 3.2500e-006
CPcor : -9.57000000e-008
Slope : 1.00000000
Offset : 0.00000

3) Frequency 2, Pressure, Digiquartz with TC

Serial number : 1214
Calibrated on : 30-Nov-16
C1 : -4.470905e+004
C2 : 3.840789e-001
C3 : 1.367850e-002
D1 : 3.661600e-002
D2 : 0.000000e+000
T1 : 3.015271e+001
T2 : -1.367200e-004
T3 : 3.926620e-006
T4 : 3.761680e-009
T5 : 0.000000e+000
Slope : 0.99999865
Offset : -1.26180
AD590M : 1.280000e-002
AD590B : -9.348400e+000

4) Frequency 3, Temperature, 2

Serial number : 1376
Calibrated on : 08-Dec-17
A : 3.68121183e-003
B : 6.00661106e-004
C : 1.51504431e-005
D : 2.12620555e-006
F0 : 6469.435
Slope : 1.00000000
Offset : 0.0000

5) Frequency 4, Conductivity, 2

Serial number : 1076
Calibrated on : 06-Dec-17
G : -4.18969113e+000
H : 5.65236010e-001
I : 3.29574520e-004
J : 1.37368013e-005
CTcor : 3.2500e-006
CPcor : -9.57000000e-008
Slope : 1.00000000
Offset : 0.00000

6) A/D voltage 0, Altimeter

Serial number : 49559

Calibrated on : 18-Feb-2010
Scale factor : 15.000
Offset : 0.000

7) A/D voltage 1, PAR/Logarithmic, Satlantic

Serial number : 1043
Calibrated on : 01-Dec-2015
a0 : 1.03324700
a1 : 0.80736900
Im : 1.35890000

8) A/D voltage 2, Oxygen, SBE 43

Serial number : 0133
Calibrated on : 01-Dec-2017
Equation : Sea-Bird
Soc : 4.04880e-001
Offset : -6.32800e-001
A : -3.54420e-003
B : 1.53460e-004
C : -2.54240e-006
E : 3.60000e-002
Tau20 : 1.01000e+000
D1 : 1.92634e-004
D2 : -4.64803e-002
H1 : -3.30000e-002
H2 : 5.00000e+003
H3 : 1.45000e+003

9) A/D voltage 3, Oxygen, SBE 43, 2

Serial number : 0042
Calibrated on : 19-Dec-2017
Equation : Sea-Bird
Soc : 4.34300e-001
Offset : -4.93300e-001
A : -3.30140e-003
B : 1.49820e-004
C : -1.91610e-006
E : 3.60000e-002
Tau20 : 1.47000e+000
D1 : 1.92634e-004
D2 : -4.64803e-002
H1 : -3.30000e-002
H2 : 5.00000e+003
H3 : 1.45000e+003

10) A/D voltage 4, Fluorometer, Seapoint Ultraviolet

Serial number : 3668
Calibrated on : 1-Jan-2015
Range : 50.000000
Offset : 0.000000

11) A/D voltage 5, Fluorometer, Seapoint

Serial number : 6210
Calibrated on : 1-Jan-2015
Gain setting : 3 x, 0-50 µg/l
Offset : 0.000

12) A/D voltage 6, pH

Serial number : 1129
Calibrated on : 12-Feb-2018
pH slope : 4.6510
pH offset : 2.5163

13) A/D voltage 7, OBS, WET Labs, ECO-BB

Serial number : 1490
Calibrated on : 9-Aug-2016
ScaleFactor : 0.002983
Dark output : 0.048000

14) SPAR voltage, Unavailable

15) SPAR voltage, SPAR/Surface Irradiance

Serial number : 1069
Calibrated on : 24-Jun-2016
Conversion factor : 1.00000000
Ratio multiplier : 1.00000000

* - The configuration was changed after the file was opened.
Scan length : 40

Appendix 1c. HUD2018004D.xmlcon (Events 37-113)

Date: 04/10/2018

Instrument configuration file:
C:\CTD_ACQUISITION\2018004HUD\ctd_con\HUD2018004D.xmlcon *

Configuration report for SBE 911plus/917plus CTD

Frequency channels suppressed : 0
Voltage words suppressed : 0
Computer interface : RS-232C
Deck unit : SBE11plus Firmware Version >= 5.0
Scans to average : 1
NMEA position data added : Yes
NMEA depth data added : No
NMEA time added : No
NMEA device connected to : deck unit
Surface PAR voltage added : Yes
Scan time added : No

1) Frequency 0, Temperature

Serial number : 5083
Calibrated on : 02-Dec-17
A : 3.68121240e-003
B : 5.97265115e-004
C : 1.50057603e-005
D : 1.97182834e-006
F0 : 2984.722
Slope : 1.00000000
Offset : 0.0000

2) Frequency 1, Conductivity

Serial number : 3562
Calibrated on : 07-Dec-17
G : -9.84211899e+000
H : 1.20149777e+000
I : -1.12798269e-003
J : 1.33106553e-004
CTcor : 3.2500e-006
CPcor : -9.57000000e-008
Slope : 1.00000000
Offset : 0.00000

3) Frequency 2, Pressure, Digiquartz with TC

Serial number : 1214
Calibrated on : 30-Nov-16
C1 : -4.470905e+004
C2 : 3.840789e-001
C3 : 1.367850e-002
D1 : 3.661600e-002
D2 : 0.000000e+000
T1 : 3.015271e+001
T2 : -1.367200e-004
T3 : 3.926620e-006
T4 : 3.761680e-009
T5 : 0.000000e+000
Slope : 0.99999865
Offset : -1.26180
AD590M : 1.280000e-002
AD590B : -9.348400e+000

4) Frequency 3, Temperature, 2

Serial number : 1376
Calibrated on : 08-Dec-17
A : 3.68121183e-003
B : 6.00661106e-004
C : 1.51504431e-005
D : 2.12620555e-006
F0 : 6469.435
Slope : 1.00000000
Offset : 0.0000

5) Frequency 4, Conductivity, 2

Serial number : 1076
Calibrated on : 06-Dec-17
G : -4.18969113e+000
H : 5.65236010e-001
I : 3.29574520e-004
J : 1.37368013e-005
CTcor : 3.2500e-006
CPcor : -9.57000000e-008
Slope : 1.00000000
Offset : 0.00000

6) A/D voltage 0, Altimeter

Serial number : 49559
Calibrated on : 18-Feb-2010

Scale factor : 15.000
Offset : 0.000

7) A/D voltage 1, PAR/Logarithmic, Satlantic

Serial number : 1043
Calibrated on : 01-Dec-2015
a0 : 1.03324700
a1 : 0.80736900
Im : 1.35890000
Multiplier : 1.00000000

8) A/D voltage 2, Oxygen, SBE 43

Serial number : 0133
Calibrated on : 01-Dec-2017
Equation : Sea-Bird
Soc : 4.04880e-001
Offset : -6.32800e-001
A : -3.54420e-003
B : 1.53460e-004
C : -2.54240e-006
E : 3.60000e-002
Tau20 : 1.01000e+000
D1 : 1.92634e-004
D2 : -4.64803e-002
H1 : -3.30000e-002
H2 : 5.00000e+003
H3 : 1.45000e+003

9) A/D voltage 3, Oxygen, SBE 43, 2

Serial number : 0042
Calibrated on : 19-Dec-2017
Equation : Sea-Bird
Soc : 4.34300e-001
Offset : -4.93300e-001
A : -3.30140e-003
B : 1.49820e-004
C : -1.91610e-006
E : 3.60000e-002
Tau20 : 1.47000e+000
D1 : 1.92634e-004
D2 : -4.64803e-002
H1 : -3.30000e-002
H2 : 5.00000e+003
H3 : 1.45000e+003

10) A/D voltage 4, Free

11) A/D voltage 5, Fluorometer, Seapoint

Serial number : 6210
Calibrated on : 1-Jan-2015
Gain setting : 3 x, 0-50 µg/l
Offset : 0.000

12) A/D voltage 6, pH

Serial number : 1129
Calibrated on : 12-Feb-2018
pH slope : 4.6510
pH offset : 2.5163

13) A/D voltage 7, OBS, WET Labs, ECO-BB

Serial number : 1490
Calibrated on : 9-Aug-2016
ScaleFactor : 0.002983
Dark output : 0.048000

14) SPAR voltage, Unavailable

15) SPAR voltage, SPAR/Surface Irradiance

Serial number : 1069
Calibrated on : 24-Jun-2016
Conversion factor : 1.00000000
Ratio multiplier : 1.00000000

* - The configuration was changed after the file was opened.
Scan length : 40

Appendix 1d. HUD2018004E.xmlcon (Events 116–159)

Date: 04/16/2018

Instrument configuration file:
C:\CTD_ACQUISITION\2018004HUD\ctd_con\HUD2018004E.xmlcon *

Configuration report for SBE 911plus/917plus CTD

Frequency channels suppressed : 0
Voltage words suppressed : 0
Computer interface : RS-232C
Deck unit : SBE11plus Firmware Version >= 5.0
Scans to average : 1
NMEA position data added : Yes
NMEA depth data added : No
NMEA time added : No
NMEA device connected to : deck unit
Surface PAR voltage added : Yes
Scan time added : No

1) Frequency 0, Temperature

Serial number : 5083
Calibrated on : 02-Dec-17
A : 3.68121240e-003
B : 5.97265115e-004
C : 1.50057603e-005
D : 1.97182834e-006
F0 : 2984.722
Slope : 1.00000000
Offset : 0.0000

2) Frequency 1, Conductivity

Serial number : 3562
Calibrated on : 07-Dec-17
G : -9.84211899e+000
H : 1.20149777e+000
I : -1.12798269e-003
J : 1.33106553e-004
CTcor : 3.2500e-006
CPcor : -9.57000000e-008
Slope : 1.00000000
Offset : 0.00000

3) Frequency 2, Pressure, Digiquartz with TC

Serial number : 1214
Calibrated on : 30-Nov-16
C1 : -4.470905e+004
C2 : 3.840789e-001
C3 : 1.367850e-002
D1 : 3.661600e-002
D2 : 0.000000e+000
T1 : 3.015271e+001
T2 : -1.367200e-004
T3 : 3.926620e-006
T4 : 3.761680e-009
T5 : 0.000000e+000
Slope : 0.99999865
Offset : -1.26180
AD590M : 1.280000e-002
AD590B : -9.348400e+000

4) Frequency 3, Temperature, 2

Serial number : 1376
Calibrated on : 08-Dec-17
A : 3.68121183e-003
B : 6.00661106e-004
C : 1.51504431e-005
D : 2.12620555e-006
F0 : 6469.435
Slope : 1.00000000
Offset : 0.0000

5) Frequency 4, Conductivity, 2

Serial number : 1076
Calibrated on : 06-Dec-17
G : -4.18969113e+000
H : 5.65236010e-001
I : 3.29574520e-004
J : 1.37368013e-005
CTcor : 3.2500e-006
CPcor : -9.57000000e-008
Slope : 1.00000000
Offset : 0.00000

6) A/D voltage 0, Altimeter

Serial number : 49559
Calibrated on : 18-Feb-2010

Scale factor : 15.000
Offset : 0.000

7) A/D voltage 1, PAR/Logarithmic, Satlantic

Serial number : 1043
Calibrated on : 01-Dec-2015
a0 : 1.03324700
a1 : 0.80736900
Im : 1.35890000
Multiplier : 1.00000000

8) A/D voltage 2, Oxygen, SBE 43

Serial number : 3030
Calibrated on : 21-Dec-2016
Equation : Sea-Bird
Soc : 4.56000e-001
Offset : -5.24800e-001
A : -3.41420e-003
B : 1.83300e-004
C : -2.88040e-006
E : 3.60000e-002
Tau20 : 1.11000e+000
D1 : 1.92634e-004
D2 : -4.64803e-002
H1 : -3.30000e-002
H2 : 5.00000e+003
H3 : 1.45000e+003

9) A/D voltage 3, Oxygen, SBE 43, 2

Serial number : 0042
Calibrated on : 19-Dec-2017
Equation : Sea-Bird
Soc : 4.34300e-001
Offset : -4.93300e-001
A : -3.30140e-003
B : 1.49820e-004
C : -1.91610e-006
E : 3.60000e-002
Tau20 : 1.47000e+000
D1 : 1.92634e-004
D2 : -4.64803e-002
H1 : -3.30000e-002
H2 : 5.00000e+003
H3 : 1.45000e+003

10) A/D voltage 4, Free

11) A/D voltage 5, Fluorometer, Seapoint

Serial number : 6210
Calibrated on : 1-Jan-2015
Gain setting : 3 x, 0-50 µg/l
Offset : 0.000

12) A/D voltage 6, pH

Serial number : 1129
Calibrated on : 12-Feb-2018
pH slope : 4.6510
pH offset : 2.5163

13) A/D voltage 7, OBS, WET Labs, ECO-BB

Serial number : 1490
Calibrated on : 9-Aug-2016
ScaleFactor : 0.002983
Dark output : 0.048000

14) SPAR voltage, Unavailable

15) SPAR voltage, SPAR/Surface Irradiance

Serial number : 1069
Calibrated on : 24-Jun-2016
Conversion factor : 1.00000000
Ratio multiplier : 1.00000000

* - The configuration was changed after the file was opened.
Scan length : 40

Appendix 1e. HUD2018004F.xmlcon (Events 161–180)

Date: 04/21/2018

Instrument configuration file:
C:\CTD_ACQUISITION\2018004HUD\ctd_con\HUD2018004F.xmlcon *

Configuration report for SBE 911plus/917plus CTD

Frequency channels suppressed : 0
Voltage words suppressed : 0
Computer interface : RS-232C
Deck unit : SBE11plus Firmware Version >= 5.0
Scans to average : 1
NMEA position data added : Yes
NMEA depth data added : No
NMEA time added : No
NMEA device connected to : deck unit
Surface PAR voltage added : Yes
Scan time added : No

1) Frequency 0, Temperature

Serial number : 5083
Calibrated on : 02-Dec-17
A : 3.68121240e-003
B : 5.97265115e-004
C : 1.50057603e-005
D : 1.97182834e-006
F0 : 2984.722
Slope : 1.00000000
Offset : 0.0000

2) Frequency 1, Conductivity

Serial number : 3562
Calibrated on : 07-Dec-17
G : -9.84211899e+000
H : 1.20149777e+000
I : -1.12798269e-003
J : 1.33106553e-004
CTcor : 3.2500e-006
CPcor : -9.57000000e-008
Slope : 1.00000000
Offset : 0.00000

3) Frequency 2, Pressure, Digiquartz with TC

Serial number : 0370
Calibrated on : 19-Jan-17
C1 : -4.274542e+004
C2 : 1.040996e-002
C3 : 1.266000e-002
D1 : 4.087300e-002
D2 : 0.000000e+000
T1 : 3.009606e+001
T2 : -6.521164e-005
T3 : 4.345040e-006
T4 : 2.428800e-009
T5 : 0.000000e+000
Slope : 0.99940215
Offset : -0.24955
AD590M : 1.289670e-002
AD590B : -8.390780e+000

4) Frequency 3, Temperature, 2

Serial number : 1376
Calibrated on : 08-Dec-17
A : 3.68121183e-003
B : 6.00661106e-004
C : 1.51504431e-005
D : 2.12620555e-006
F0 : 6469.435
Slope : 1.00000000
Offset : 0.0000

5) Frequency 4, Conductivity, 2

Serial number : 1076
Calibrated on : 06-Dec-17
G : -4.18969113e+000
H : 5.65236010e-001
I : 3.29574520e-004
J : 1.37368013e-005
CTcor : 3.2500e-006
CPcor : -9.57000000e-008
Slope : 1.00000000
Offset : 0.00000

6) A/D voltage 0, Altimeter

Serial number : 49559
Calibrated on : 18-Feb-2010

Scale factor : 15.000
Offset : 0.000

7) A/D voltage 1, PAR/Logarithmic, Satlantic

Serial number : 1043
Calibrated on : 01-Dec-2015
a0 : 1.03324700
a1 : 0.80736900
Im : 1.35890000
Multiplier : 1.00000000

8) A/D voltage 2, Oxygen, SBE 43

Serial number : 3030
Calibrated on : 21-Dec-2016
Equation : Sea-Bird
Soc : 4.56000e-001
Offset : -5.24800e-001
A : -3.41420e-003
B : 1.83300e-004
C : -2.88040e-006
E : 3.60000e-002
Tau20 : 1.11000e+000
D1 : 1.92634e-004
D2 : -4.64803e-002
H1 : -3.30000e-002
H2 : 5.00000e+003
H3 : 1.45000e+003

9) A/D voltage 3, Oxygen, SBE 43, 2

Serial number : 0042
Calibrated on : 19-Dec-2017
Equation : Sea-Bird
Soc : 4.34300e-001
Offset : -4.93300e-001
A : -3.30140e-003
B : 1.49820e-004
C : -1.91610e-006
E : 3.60000e-002
Tau20 : 1.47000e+000
D1 : 1.92634e-004
D2 : -4.64803e-002
H1 : -3.30000e-002
H2 : 5.00000e+003
H3 : 1.45000e+003

10) A/D voltage 4, Free

11) A/D voltage 5, Fluorometer, Seapoint

Serial number : 6210
Calibrated on : 1-Jan-2015
Gain setting : 3 x, 0-50 µg/l
Offset : 0.000

12) A/D voltage 6, pH

Serial number : 1129
Calibrated on : 12-Feb-2018
pH slope : 4.6510
pH offset : 2.5163

13) A/D voltage 7, OBS, WET Labs, ECO-BB

Serial number : 1490
Calibrated on : 9-Aug-2016
ScaleFactor : 0.002983
Dark output : 0.048000

14) SPAR voltage, Unavailable

15) SPAR voltage, SPAR/Surface Irradiance

Serial number : 1069
Calibrated on : 24-Jun-2016
Conversion factor : 1.00000000
Ratio multiplier : 1.00000000

* - The configuration was changed after the file was opened.
Scan length : 40

s.19(1)

Appendix 2. Crew List

CCGS Hudson Crew List — South Crew

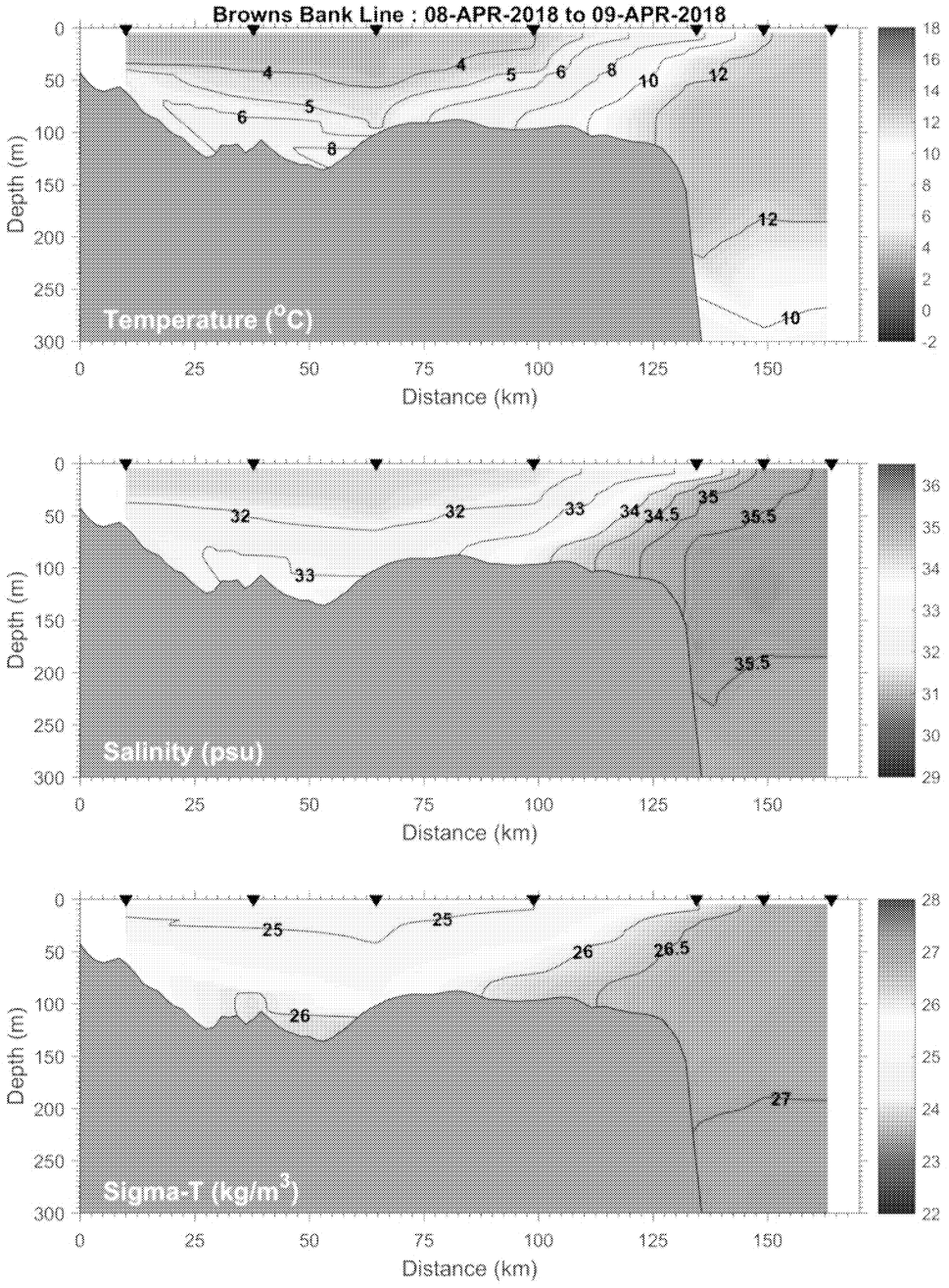
05 April 2018 — Total on board: ~~32~~ 48

Position	Surname	Given Name	Cabin	Cabin Phone #
Commanding Officer	Cotie	Richard	12	200
Chief Officer			14	204
Second Officer			19	205
Third Officer			17	203
Boatswain	Coolen	Richard	106	234
Leading Seaman 1			65	216
Leading Seaman 2			70	222
Leading Seaman 3	Johnson	Donald	67	217
Leading Seaman 4			76	224
Seaman 1			69	218
Seaman 2			78	225
Seaman 3			88	229
Seaman 4			86	228
Seaman 5			84	227
Chief Engineer	Van Der Baaren	Richard	108	235
Senior Engineer	Coady	Justin	122	242
First Engineer	Hardy	Matthew	110	239
Second Engineer			121	243
Third Engineer			123	240
Supernumerary Engineer			113	238
Electrical Officer			124	246
Oiler 1			111	237
Oiler 2			109	236
Logistics Officer	Higgins	Leo	13	201
Storekeeper			105	233
Chief Cook			89	232
Second Cook			139	250
Cook/Steward			137	249
Cook/Steward			87	231
Steward 1			133	247
Steward 2			135	248
Steward 3			50	137
Medical Officer			50	137
Electronics Technician	Hughes	Andrew	112	244
Cadet #1	Trout	Spencer	66	220
Cadet #2	Gallant	Jacob	68	221
Senior Scientist	Cogswell	Andrew	35	206
Science Staff (Cabin 36)	Waclawik	Magda	36	208
Science Staff (Cabin 36)	Wilson	Colleen	36	208
Science Staff (Cabin 37)	Thamer	Peter	37	207
Science Staff (Cabin 38)	Layton	Chantel	38	213
Science Staff (Cabin 39)	Benjamin	Robert	39	209
Science Staff (Cabin 40)	Winkel	Jeannine	40	214
Science Staff (Cabin 41)			41	210
Science Staff (Cabin 42)	MacIsaac	Kevin	42	215
Science Staff (Cabin 43)	Perry	Tim	43	211
Science Staff (Cabin 45)	Spry	Jeff	45	212
Science Staff (Cabin 115)	Levy	Dave	115	241
Science Staff (Cabin 125)	Cormier	Terry	125	245
Science Staff (Cabin 136)			136	252
Science Staff (Cabin 141)			141	251

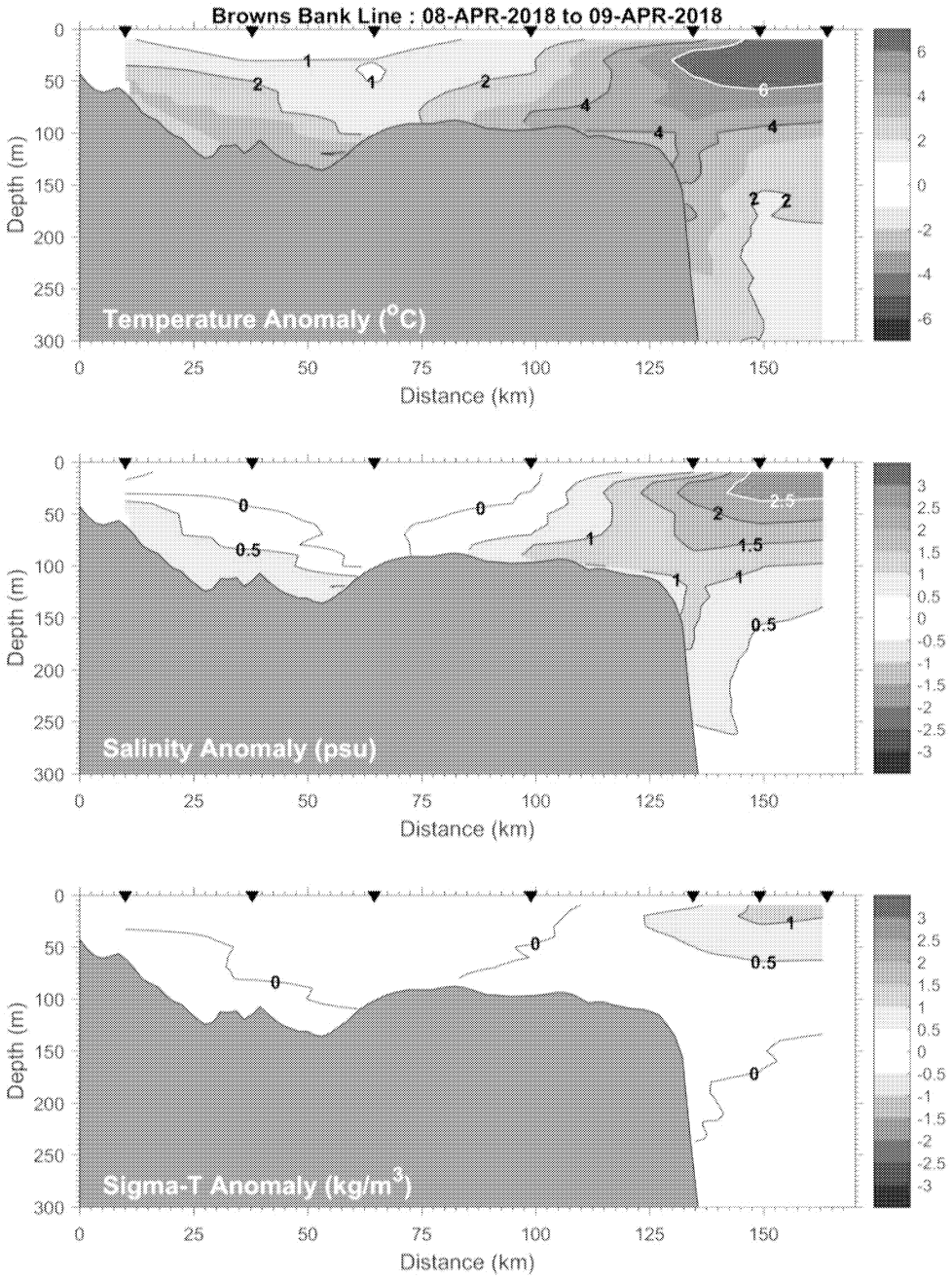
Appendix 3. Preliminary Section Plots and Anomalies (T/S/Sigma-T)

Browns Bank Line

Section

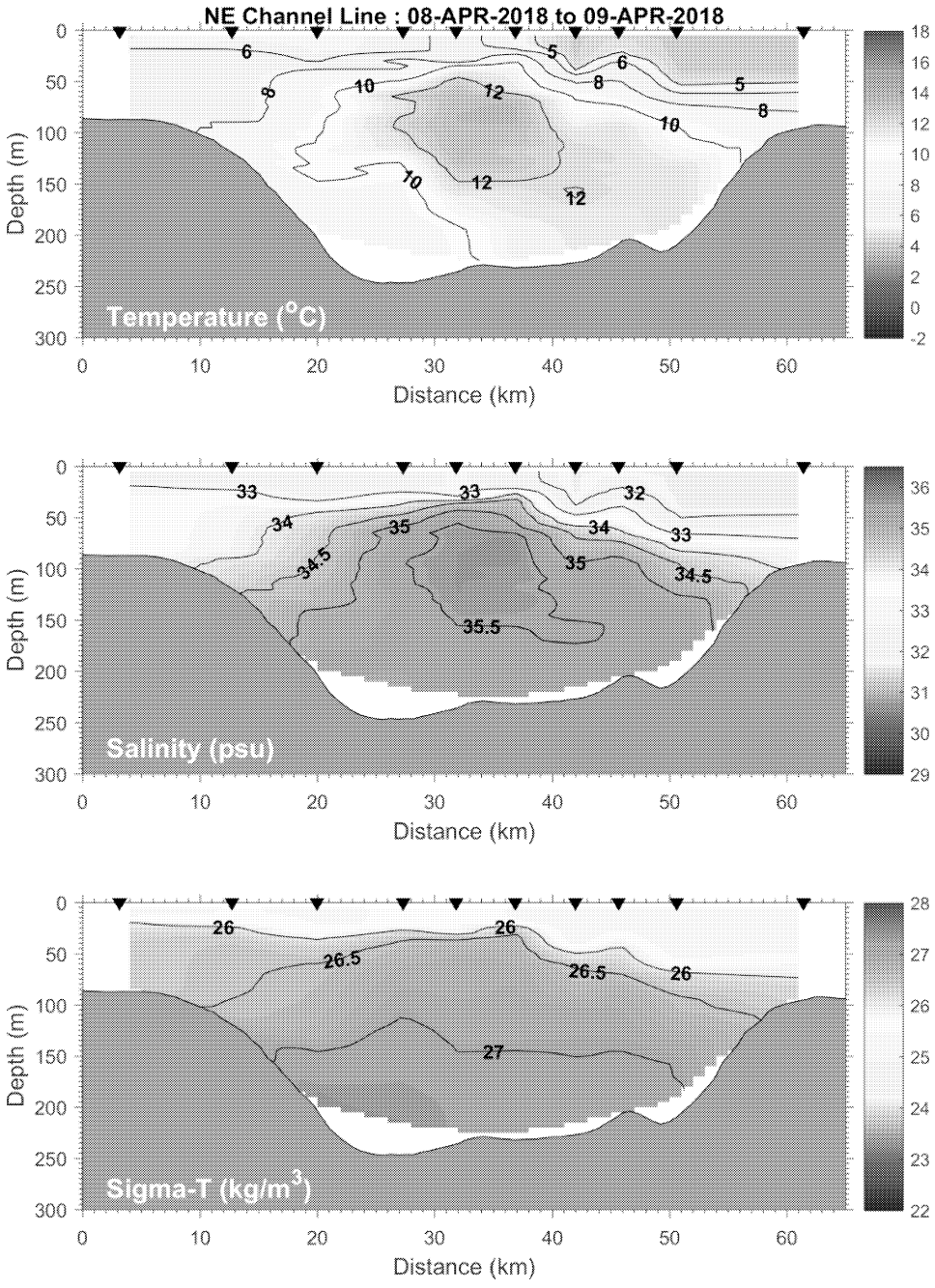


Anomaly

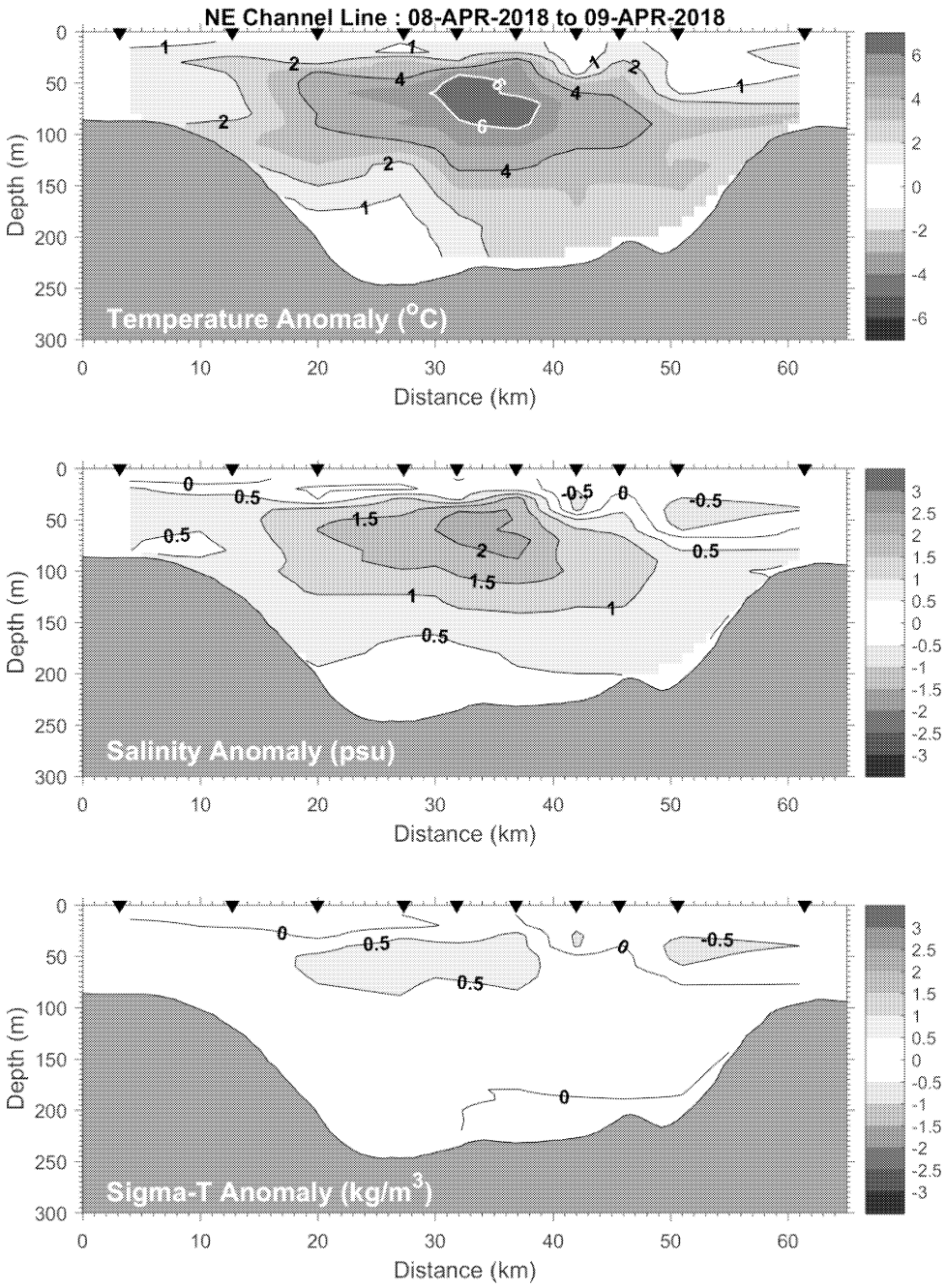


Peter Smith Line

Section

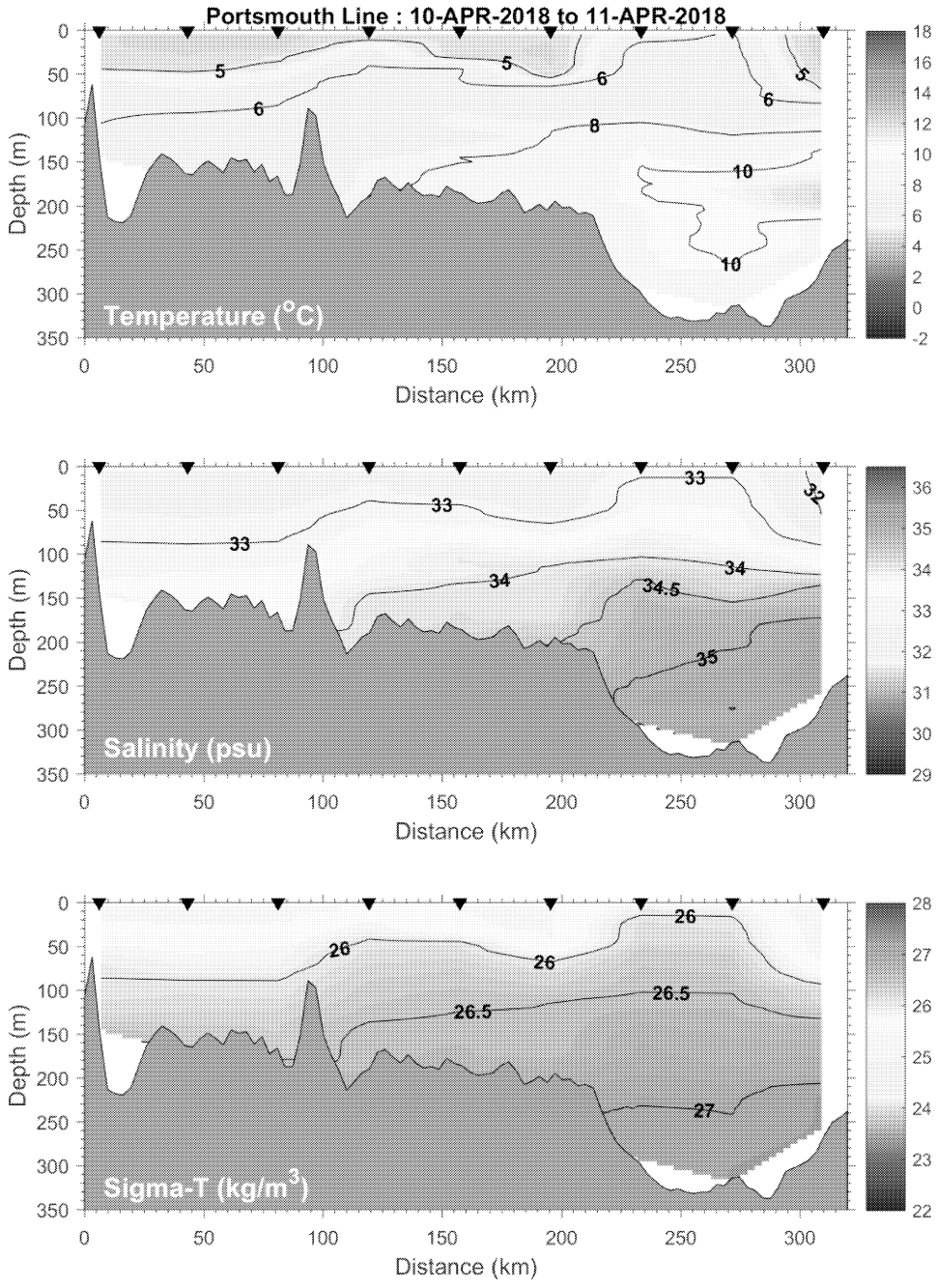


Anomaly



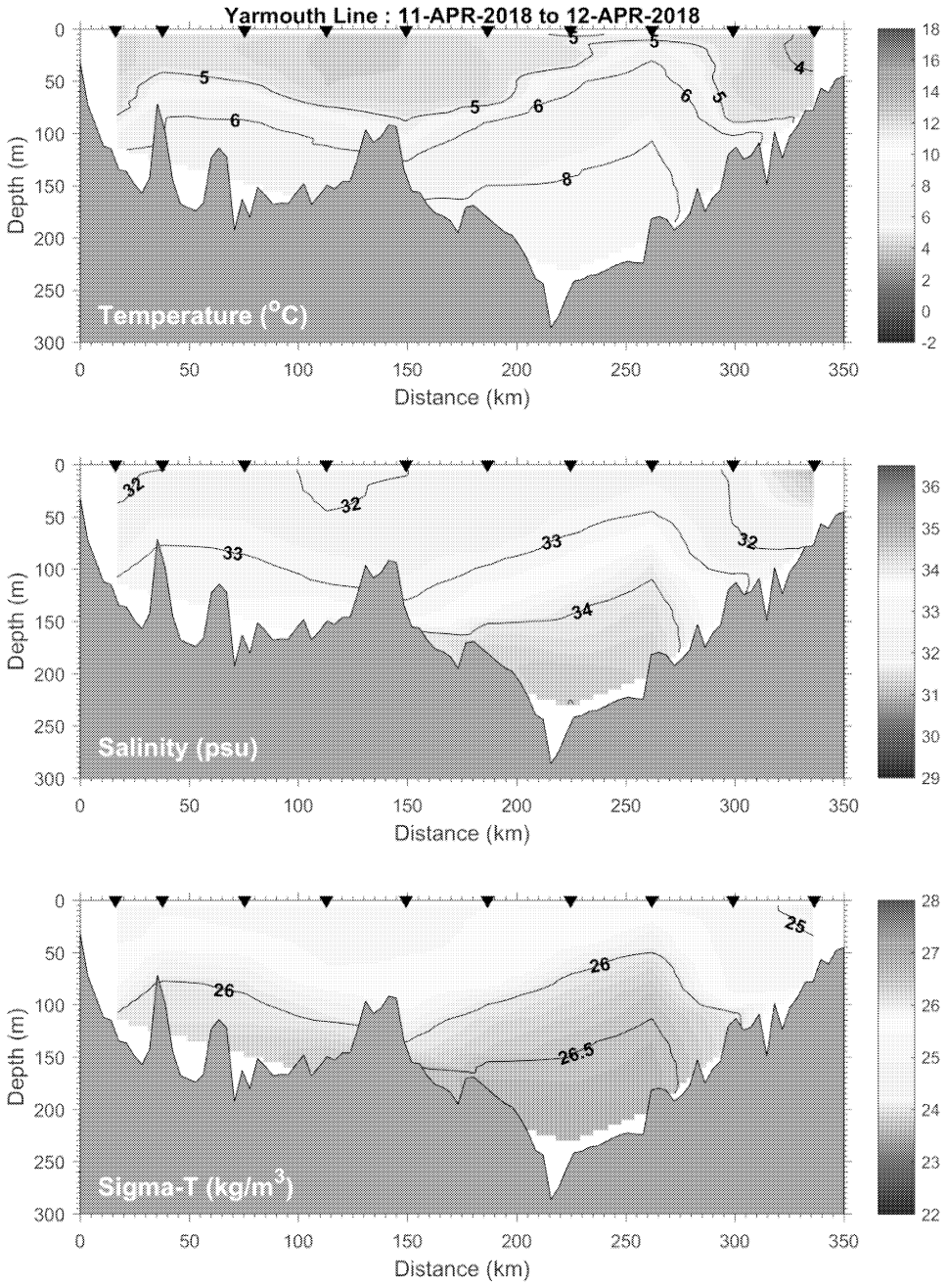
Portsmouth Line

Section



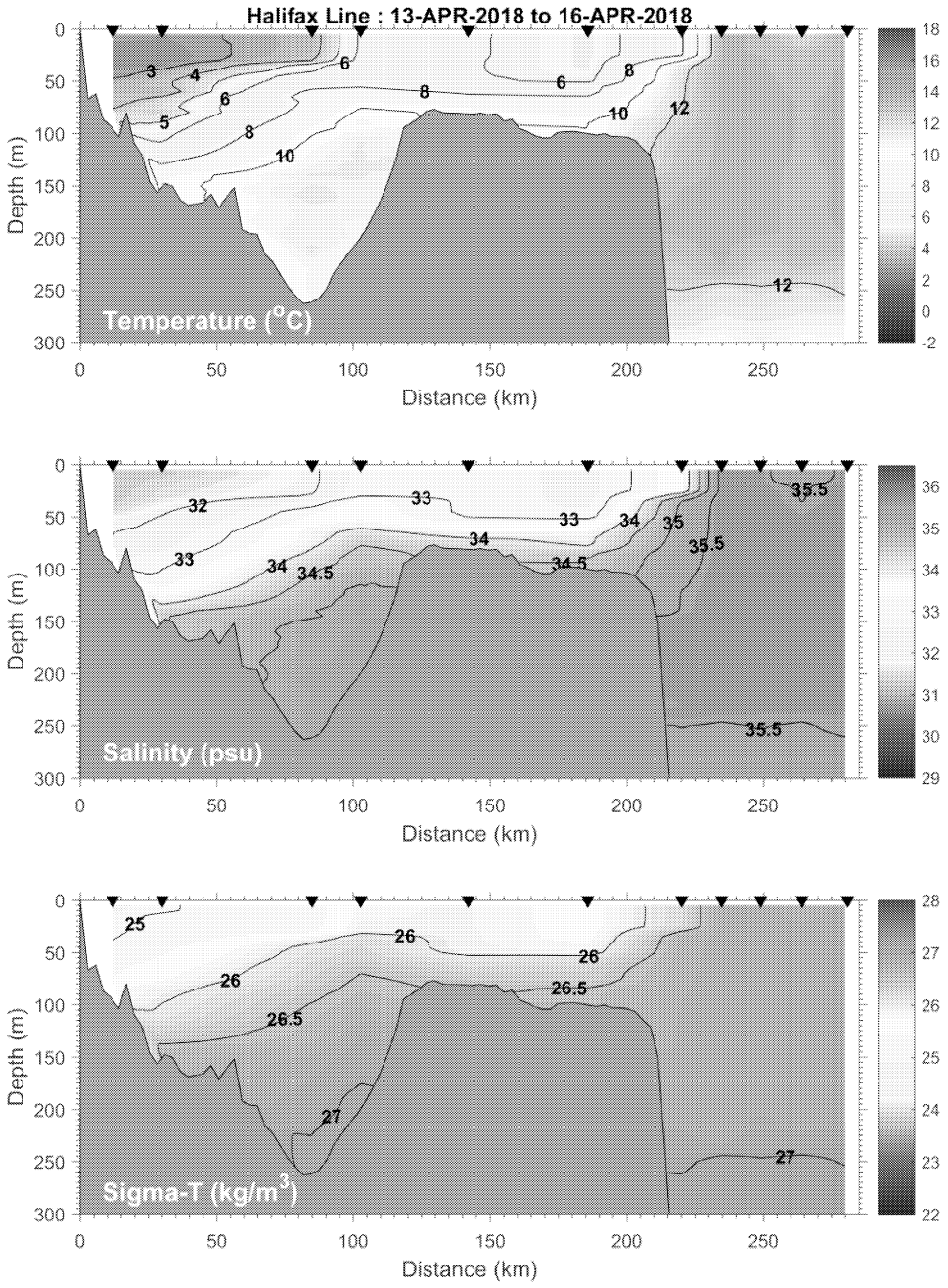
Yarmouth Line

Section



Halifax Line

Section



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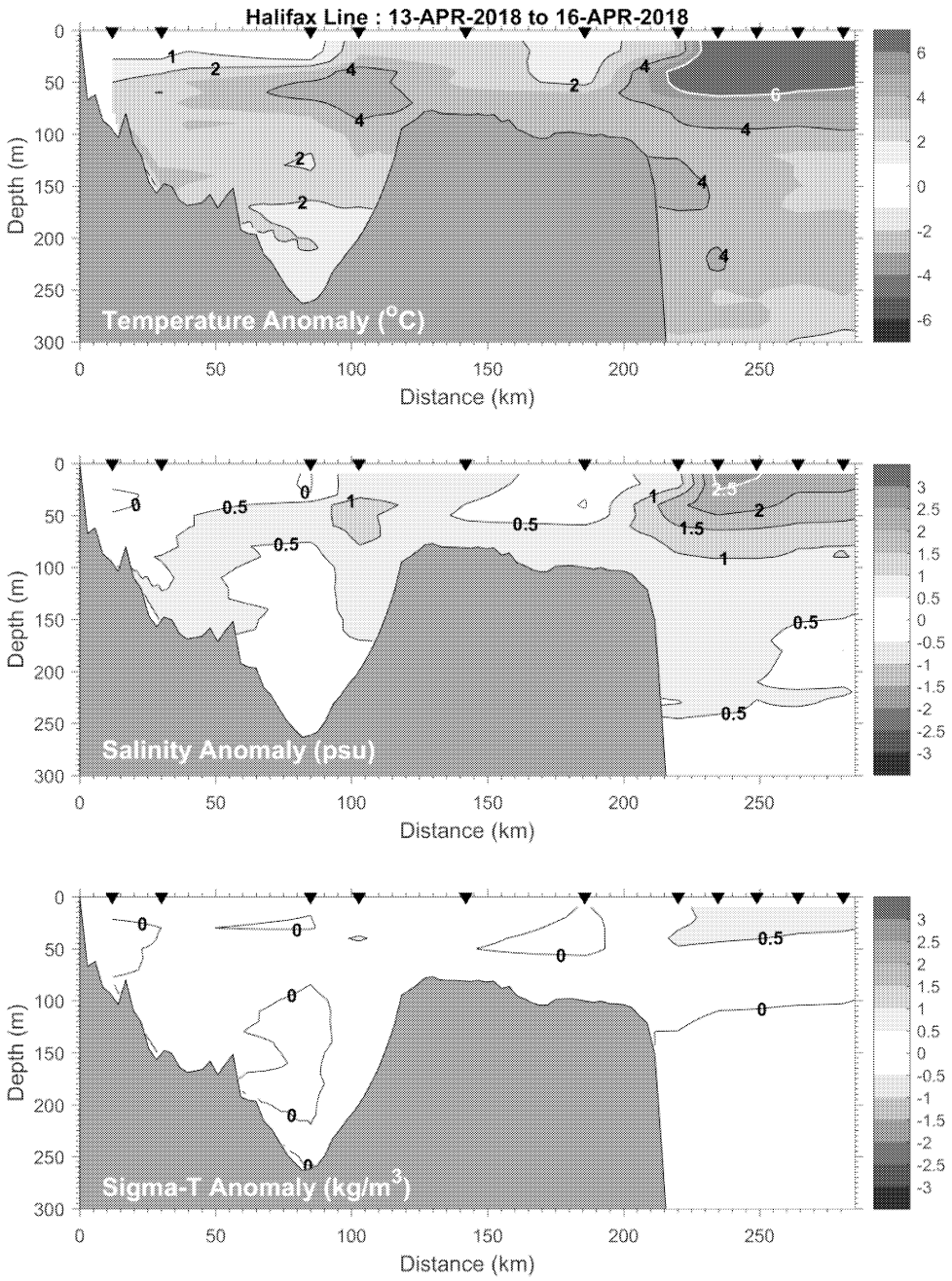
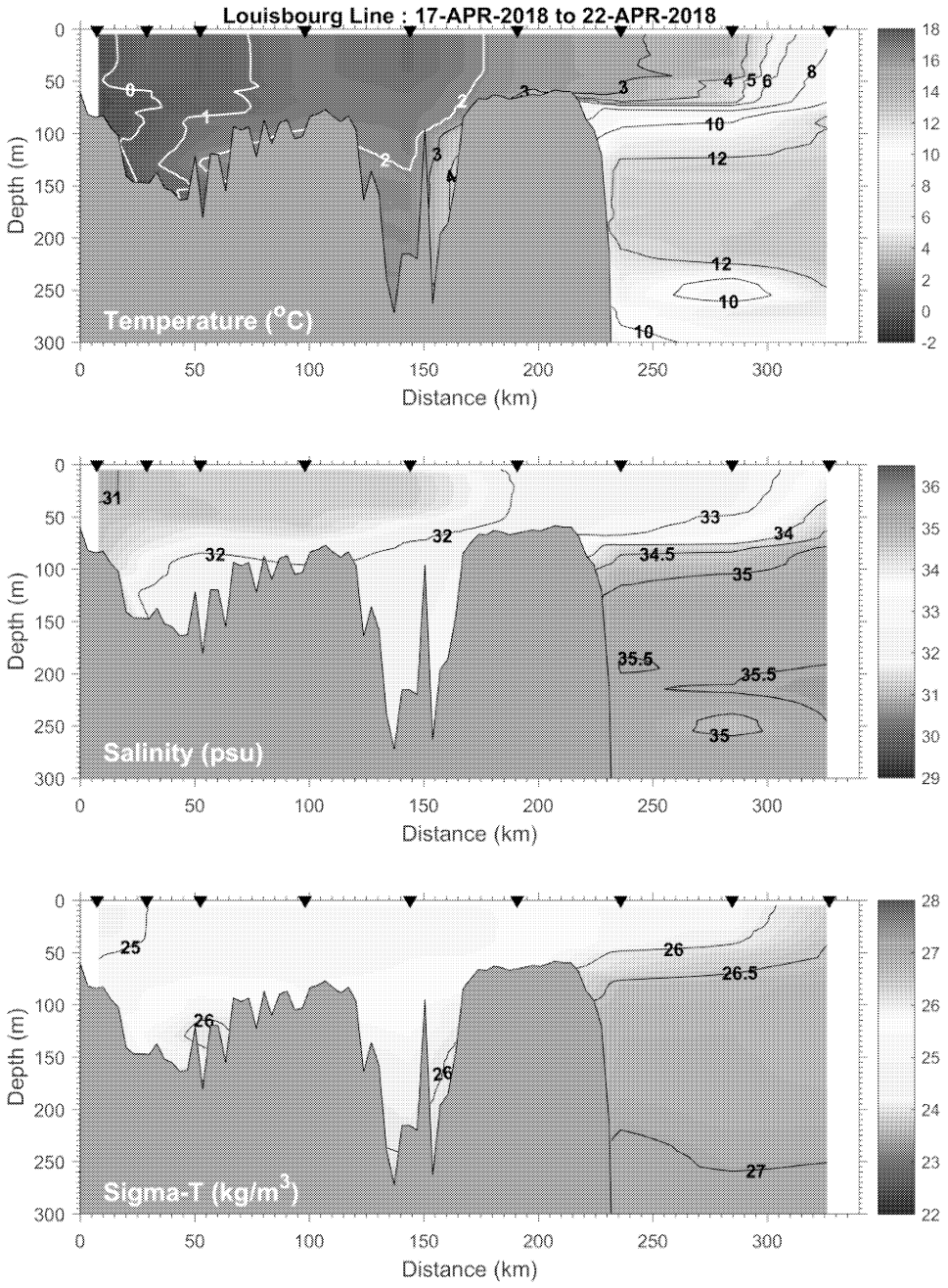


Louisbourg Line

Section



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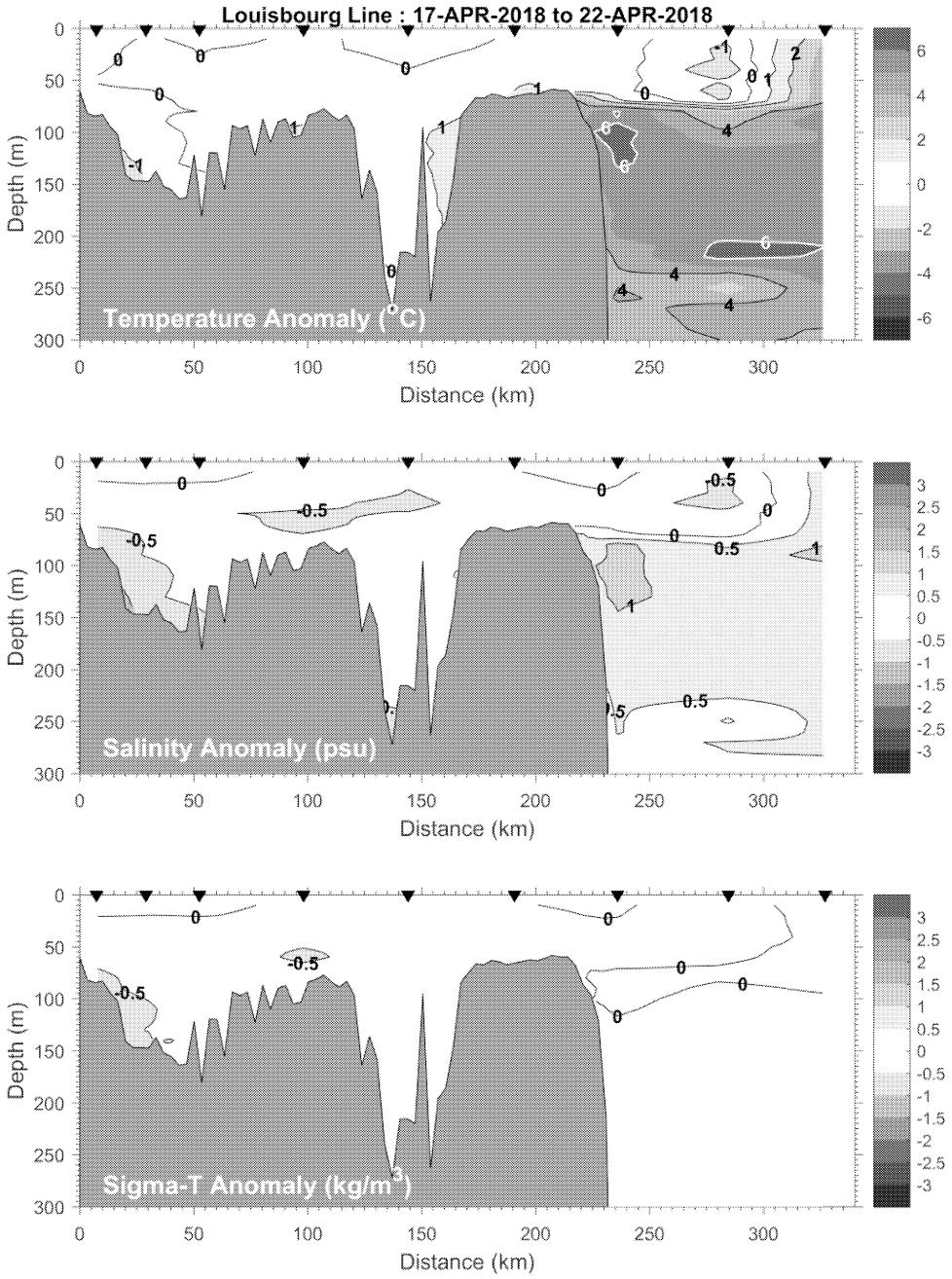
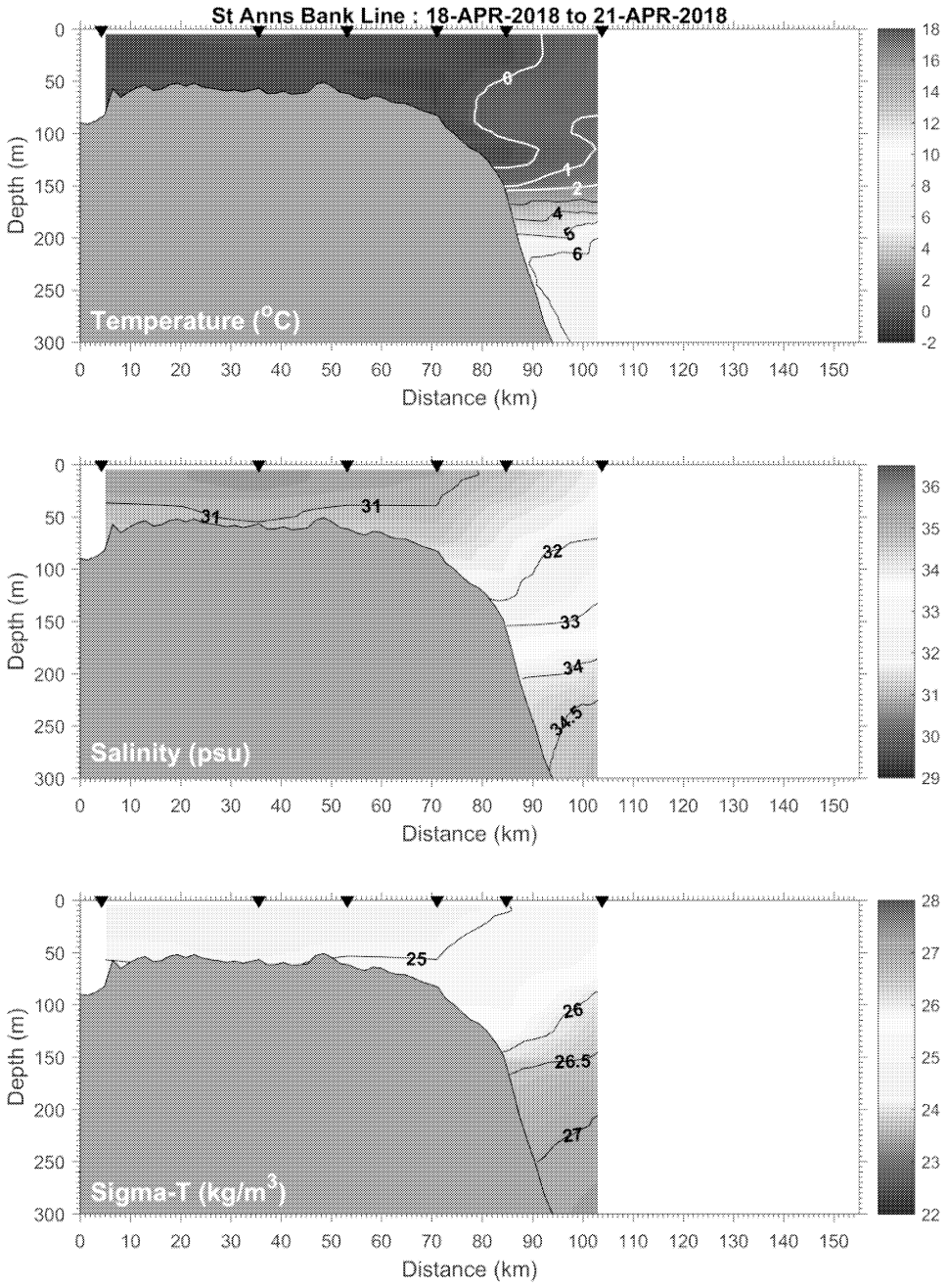


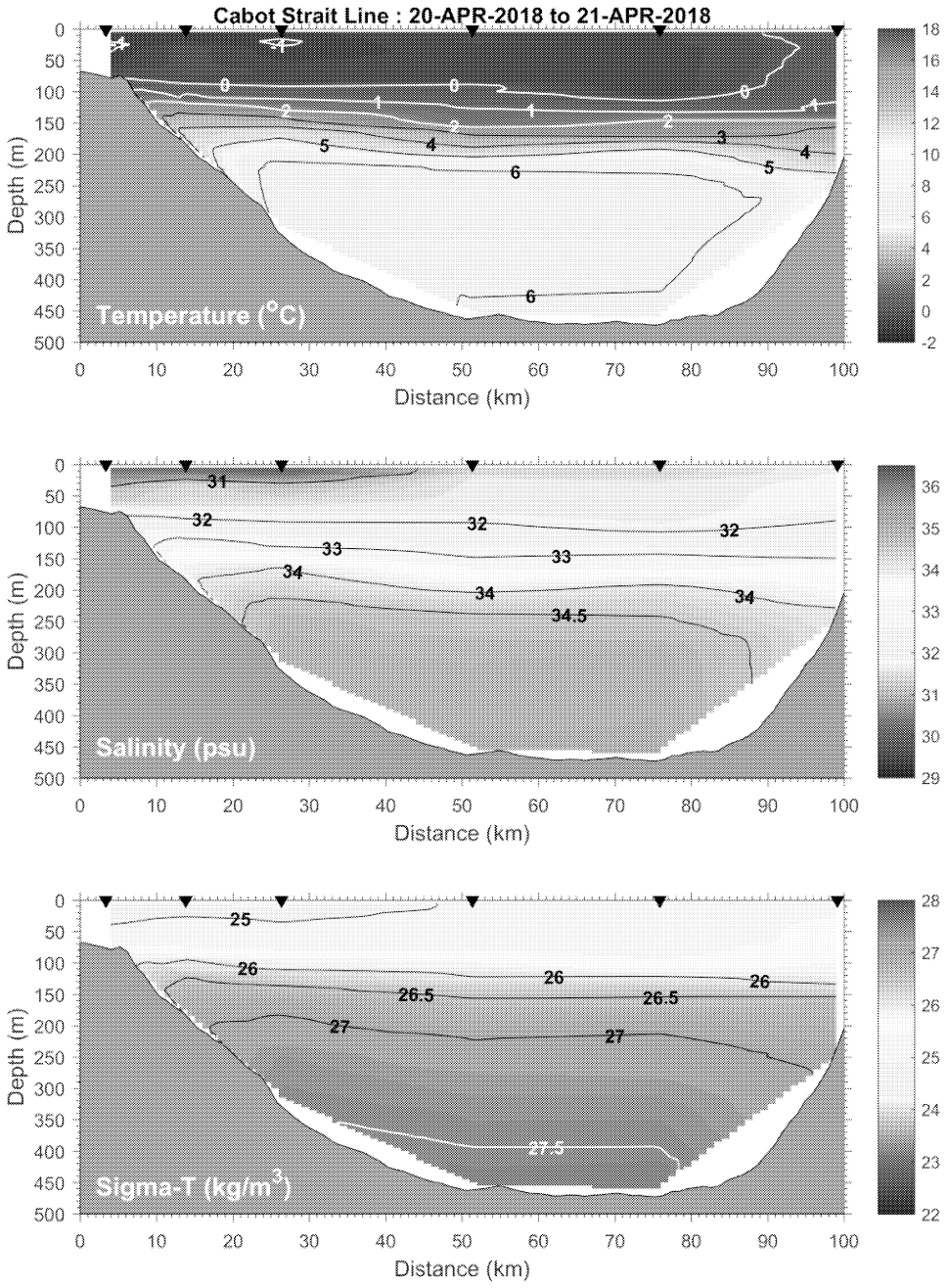
St. Anns Bank Line

Section



Cabot Strait Line

Section



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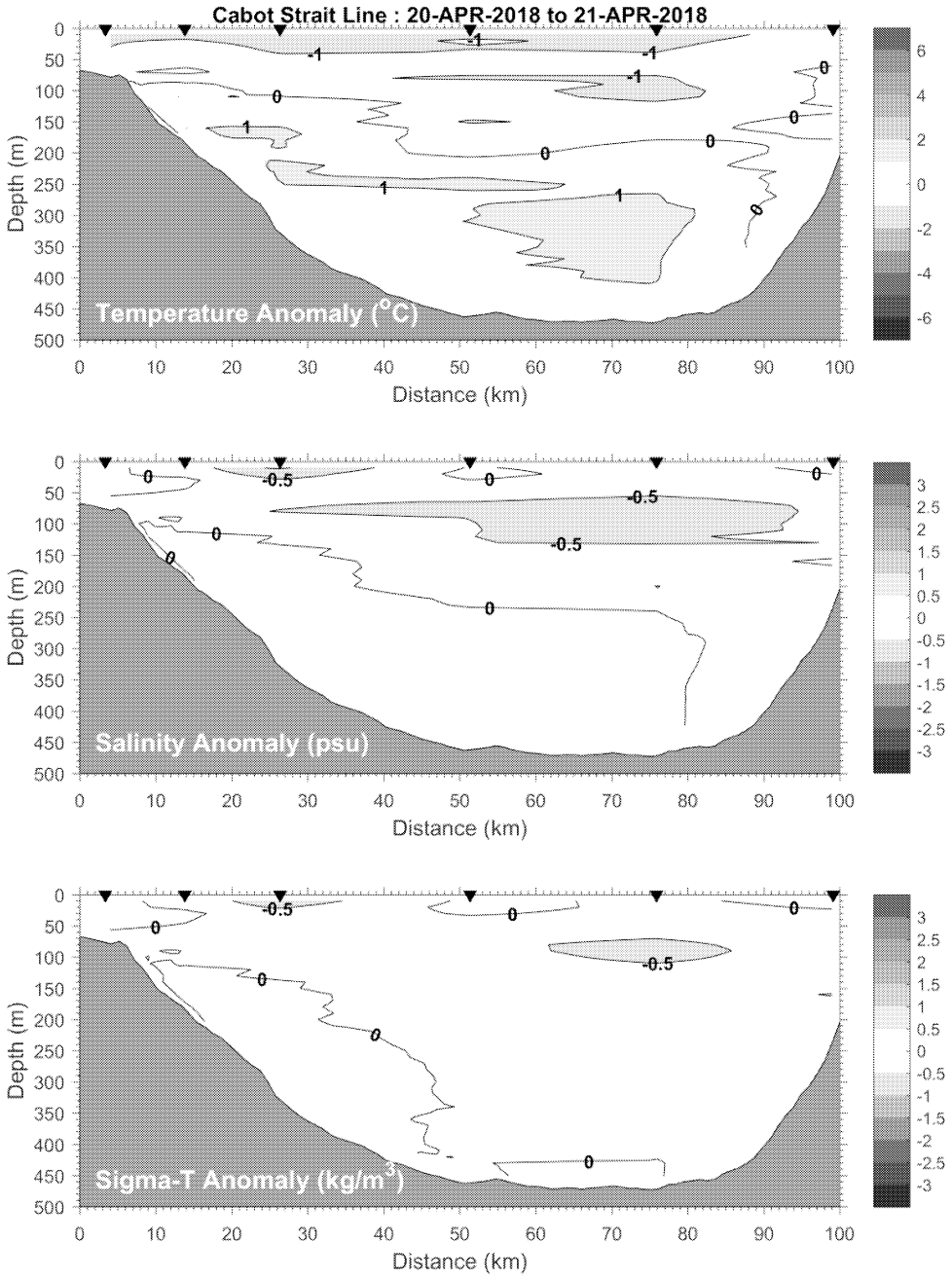
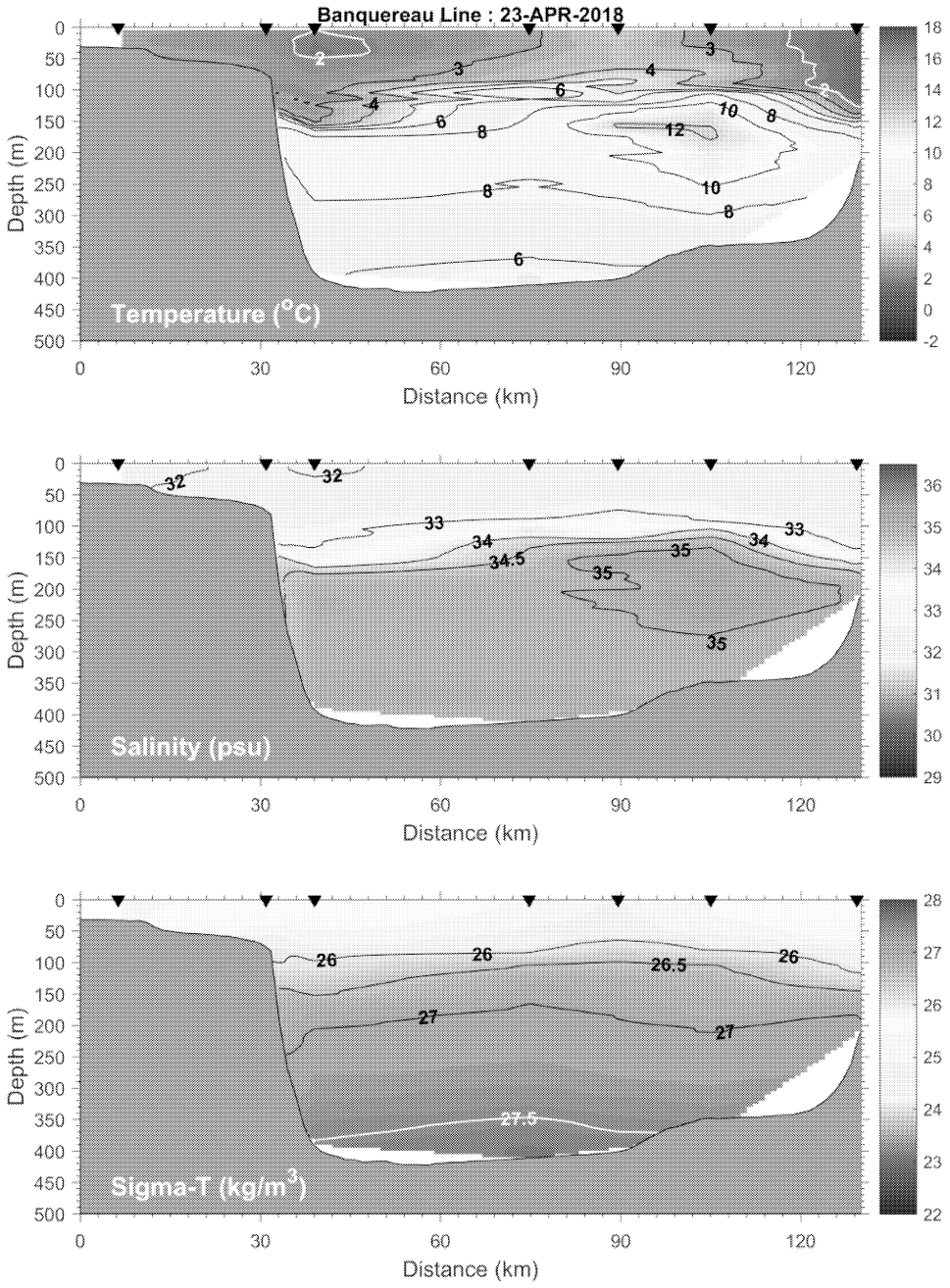
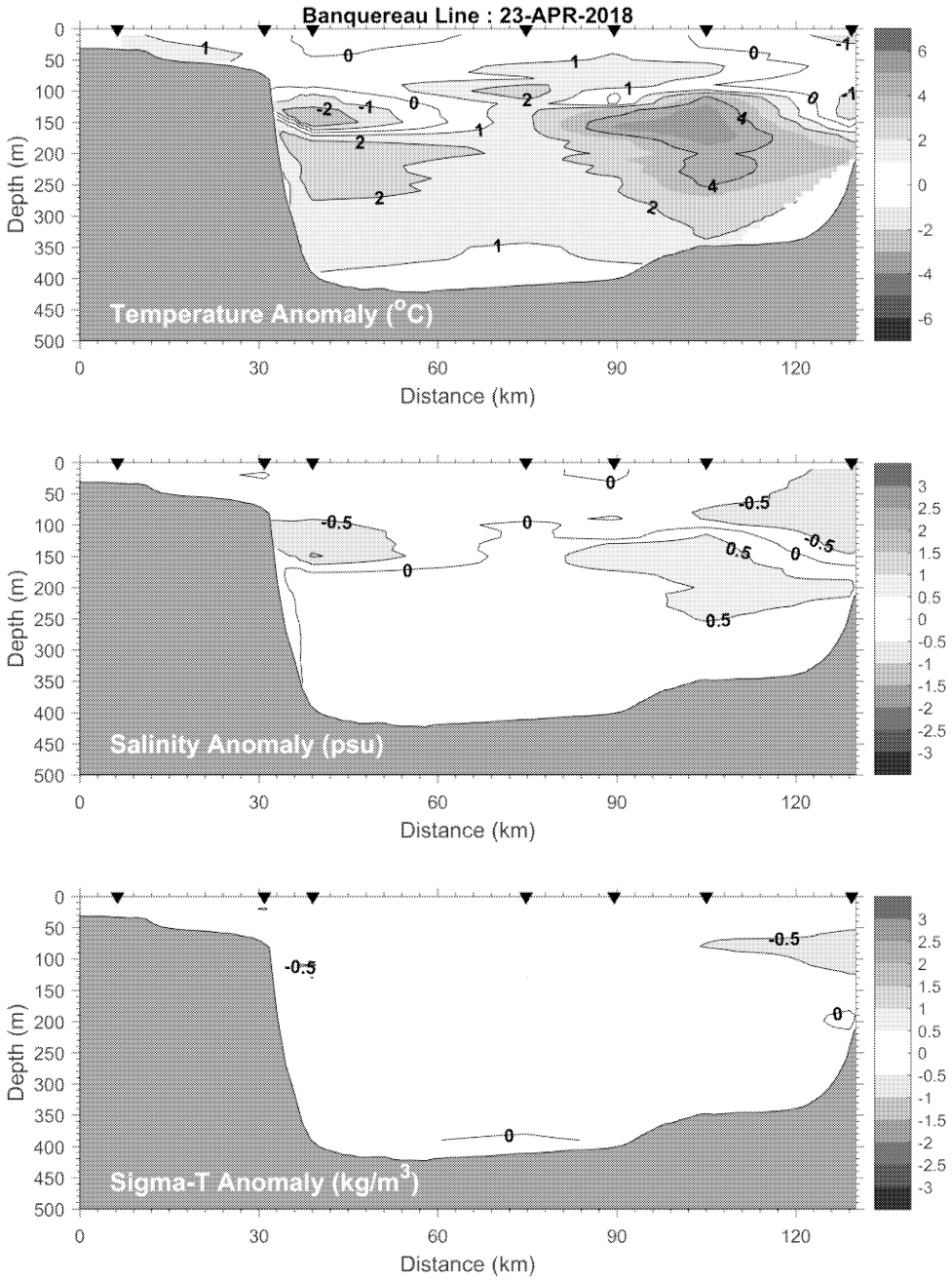


Brian Petrie/Banquereau Line

Section



Anomaly



Fisheries and Oceans Canada | Pêches et Océans Canada
Ecosystems and Oceans Science | Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2018/nnn

Maritimes Region

St. Anns Bank Framework Assessment

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DRAFT: July 26, 2018

Canada

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044

Correct citation for this publication:

Choi, J.S., Vanderlaan, A.S.M., Lazin, G., McMahon, M., Zisserson, B., Cameron, B., and Munden, J. 2018. St. Anns Bank Framework Assessment. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/nnn. vi + 65 p.

Aussi disponible en français : *(only if the Research Document is to be translated)*

Choi, J.S., Vanderlaan, A.S.M., Lazin, G., McMahon, M., Zisserson, B., Cameron, B., et Munden, J. 2018. Titre – doit correspondre exactement à la page couverture. Secr. can. de consult. sci. du MPO. Doc. de rech. 2018/nnn. vi + xx p.

TABLE OF CONTENTS

ABSTRACT

This analysis is intended to begin the dialogue required to develop a framework for monitoring and assessing spatially managed areas such as Marine Protected Areas (MPAs). In particular, we begin with the *Oceans Act* requirement to describe productivity, biodiversity, habitat and species of interest by identifying pragmatic metrics of these ecosystem-level attributes from pre-existing monitoring systems in the area of interest: St. Anns Bank in the Maritimes Region of Canada. We also identify a few human influences/pressures that are also readily quantified, namely fishing and vessel activity and some of the data gaps that are evident in the area. The nature of these data, and the steps required to use them properly, are made explicit in an open-sourced and revision-controlled environment (R and git) for the purpose of developing a transparent, vetted data and code system from which future assessment and modeling attempts can be staged. This should reduce the replication of effort in future. The rationale for the methods chosen to quantify the characteristic space and time scales of processes and features are identified and discussed. Ultimately, the intent is to develop approaches similar to the risk-based approach frequently encountered in fishery stock assessments, such that we can begin to express the "status" of an area or MPA. It is perhaps even possible to attempt to define reference points and obtain a better sense of the "health" of these areas, or at least assess the relative influence of area-based management closures. This first report will focus only upon the "Data" side of the issues and clarify the proposed "Methods".

INTRODUCTION

TERMS OF REFERENCE

The Health of the Oceans (2007) initiative and the National Conservation Plan (2014) support the conservation and restoration of lands and waters in Canada. In this context, the Science Branch of the Department of Fisheries and Oceans (DFO), has been tasked with developing a monitoring approach for Marine Protected Areas (MPAs) and, if possible, to assess their effectiveness in meeting their objectives.

SCOPE OF THIS REPORT

An Marine Protect Area (MPA) is defined in the *Oceans Act 35(1)* as, "An area of the sea that forms part of the internal waters of Canada, the territorial sea of Canada or the Exclusive Economic Zone of Canada and has been designated under this section for special protection for one or more of the following reasons:

- *conservation and protection* of commercial and non-commercial fishery resources, including marine mammals, and their habitats;
- *conservation and protection* of endangered or threatened marine species, and their habitats;
- *conservation and protection* of unique habitats;
- *conservation and protection* of marine areas of high biodiversity or biological productivity; and
- *conservation and protection* of any other marine resource or habitat as is necessary to fulfill the mandate of the Minister."

As a result, for the purposes of this report, we will likewise focus upon these key ecosystem attributes or components, namely: **productivity, biodiversity, habitat, and species of interest**. In reality, however, there are many other attributes or components of ecosystems that are also known to be important and relevant, including: ecological integrity and health, trophic structure and balance, ecosystem function, complexity, network structure, resilience, sustainability, as well as an open-ended number of species or life-history stages of the resident species. These other components will be touched upon where possible or necessary.

ST. ANNS BANK

The St. Anns Bank Marine Protected Area (herein, SAB) is an area of interest for eventual designation as an MPA. It is located east of Cape Breton Island, Nova Scotia, Canada (Figure 1). Previous advisory processes (DFO 2012; Kenchington 2013), identified the primary objectives of SAB as being to conserve, protect and, where appropriate, restore ecologically distinctive or significant areas and, overall, the ecosystem "health" of SAB. As in the *Oceans Act*, the focus was upon the above four ecosystem components: **productivity, biodiversity, habitat and species of interest**.

Other MPA goals were also expressed in DFO (2012) and Kenchington (2013), but these were less emphatic:

- *contribute* to the health, resilience and restoration of the Eastern Scotian Shelf ecosystem;
- *contribute* to the recovery and sustainability of commercial fisheries; and
- *promote* scientific research and monitoring to further understand and protect SAB.

Ford and Serdynska (2013) make more precise the ecological components that the SAB area of interest might help to protect and conserve, especially in the context of the definition of MPAs in the *Oceans Act*:

- commercial and non-commercial fishery resources, including marine mammals, and their habitats (e.g., habitat for Atlantic Cod, redfish, American Plaice, sea urchins, White Hake, Witch Flounder, sea anemones, sponges, and sea pens);
- Endangered or Threatened marine species, and their habitats (e.g., habitat for depleted species such as Atlantic Wolffish, Atlantic Cod, and Leatherback Turtles);
- unique habitats (it is the only major bank on the Inner Scotian Shelf); and
- marine areas of high biodiversity or biological productivity of invertebrates and fish.

OBJECTIVES

The **primary objectives** of this report are to:

- Develop an Assessment Framework that can
  - monitor the status of an MPA; and
  - assess the effectiveness of an MPA in meeting its conservation objectives.
- Identify data gaps and sources of uncertainty.

The method by which this can be accomplished, however, is anything but straightforward. This is primarily due to the fact that the SAB is:

- a large ecosystem and as such complex, operating at various space, time and organizational scales;
- connected in various ways to the surrounding environment and so cannot be treated as an isolated system; and
- measures of system components of interest, namely, productivity, biodiversity, habitat and species of interest, are ambiguous and imperfect at best, and usually non-existent or poor in information quality and/or quantity.

As such, we emphasize that this report is a simplistic first attempt at developing a general approach towards assessing MPAs. Indeed, given the above significant challenges, it is best viewed as a work in progress that will require further precision and improvement. To this end, we will, in the following, describe the data used for the assessment; outline the methods and assumptions associated with the modeling of this data; summarize the primary results of this analysis; provide some discussion of salient points; and conclude with general recommendations. The technical aspects of data Quality Assurance (QA)/Quality Control (QC), associated assumptions and methods are identified in the Appendices.

NOTE: The primary purpose of this document is the Data and Methods. Results and Discussions will be the focus of a subsequent paper.

DATA

In this section, we focus upon a description of the data chosen for inclusion in this assessment. The purpose of the section is to clearly identify the data, sampling design, and the associated assumptions and methods required/used to filter and integrate them in an informative manner.

For the sake of transparency, all data assimilation and QA/QC methods have been encoded in an open-sourced analytical environment R (R Core Team 2015) and made publicly accessible at GitHub (packages under development) and to permit flexible and adaptive multiuser contributions through the **Git** revision control system and a uniform data interface system. This approach permits the development of a coherent and vetted approach that is completely open source in nature. In this way, we see this project as a real and flexible structural and collaborative framework in the sense of a real scaffolding, to build a monitoring and assessment system that can be easily transferred to other regions, domains and mandates, as well as, fostering collaborations and communication with universities and the general public.

STUDY AREA

Evaluating MPA status and effectiveness in meeting conservation objectives, requires explicit reference to changes both within and without the area of interest. Even in the most basic BACI-type design, this requirement is explicit (Green 1979; Underwood 1992). For this reason, and also to facilitate evaluations of other potential MPAs in the region, a much larger surrounding area was chosen for analytical purposes. This area is the continental shelf region of Nova Scotia (Figure 2), bounded by latitudes 37°N to 48°N and longitudes from 48°W to 71°W. [Note: It should be emphasized that this will not alleviate problems associated with pseudo-(spatial, temporal) replication (Hurlbert 1984), although an assumption of a Gaussian process (see Methods) may potentially alleviate this problem.]

DATA SELECTION CRITERIA

Exhaustive surveys of available data have been compiled by Ford and Serdynska (2013). Their conclusions were that most biological data and environmental conditions are poorly sampled in the SAB area. The decision criteria for inclusion of data in this study were as follows:

- Part of an **on-going sampling** program. This is because the design principle behind this project is that the underlying assessment must smoothly transition into a routine monitoring approach into the future.
- Sufficient and regular **spatial** coverage (> 100 sampling locations) inside MPA and throughout the study area.
- Sufficient and regular **temporal** coverage (approximately annually, > 10 years) inside MPA and throughout the study area.
- **Informative** – high data quality that is in some manner related to productivity, biodiversity, habitat and species of interest.

The same decision criteria were applied to human usage data. The result was to include the following data streams for MPA characterisation:

- Atlantic Zone Monitoring Program (AZMP)/chlorophyll-a and nutrients: BioChem bottle data (Devine et al. 2014).
- AZMP/Zooplankton: BioChem database (Devine et al. 2014).
- Remote Sensing Data: ocean colour and SST (Remote Sensing Group).
- Groundfish: DFO's Groundfish Research Vessel surveys focus upon demersal fish species, since approximately 2000, upon invertebrates as well.
- Snow Crab survey, focus upon benthic invertebrates.

- Clam survey data in Banquereau and Western banks (though it does not pass the temporal coverage conditions, it offers very high resolution multispecies data on the banks).
- Temperature records: from various sources, especially, groundfish, Snow Crab and AZMP surveys.
- Salinity (Groundfish surveys/AZMP, BioChem).
- Oxygen and pH (once the data have been reloaded; Groundfish surveys/AZMP, BioChem).
- Bathymetry (CHS, Groundfish survey, Snow Crab survey).

To characterise human usage patterns, the following have been chosen for inclusion:

- Logbook records of catch and effort (MARFIS/ZIFF).
- AIS tracks – Radio-based Automatic Identification System.
- VMS potentially – Satellite-based Vessel Monitoring System.

DISCRETE BOTTLE DATA: CHLOROPHYLL-A AND NUTRIENTS

- Relevance: productivity, biodiversity, habitat and species of interest (in relative order).
- Sampling: AZMP surveys, Groundfish surveys, pelagic net tows and water profiles.
- Spatial coverage: variable no. stations, 143,499 records, 829 missions.
- Temporal coverage: 1955 to present, annual surveys.
- Source code: https://github.com/jae0/aegis/
- Discrete bottle data consisting of chlorophyll-a and nutrient records (nitrate, phosphate and silicate) were obtained by laboratory analysis of water samples collected at discrete depths. For this study all available nutrient and chlorophyll-a discrete bottle data were extracted from DFO's BioChem database for the study area. This dataset contains more than 500,000 records with the earliest records starting in 1955. After QA/QC, the discrete bottle data retained for analysis was comprised of 143,499 profiles, collected on 829 missions (Figure 3; Appendix 1).

The number of profiles available in each year (Figure 4) shows that there were few profiles taken until the mid-1960s, and a relatively steady number of yearly profiles after the initiation of the AZMP in 1999. The peak sampling during the period 1976-1982 corresponds to DFO's Scotian Shelf Ichthyoplankton Program (SSIP) and foreign research vessels sampling programs that were obtained from the National Oceanic and Atmospheric Administration's (NOAA) National Oceanographic Data Center (Pierre Clement, personal communication). Monthly distribution of the profiles (Figure 5) demonstrates that most of the data was collected in July (mostly during DFO's groundfish surveys), followed by the months of September and April. Note that spatial distribution of the sampling varies among months with most data collected on the Scotian Shelf in July and the fewest data in January (Figure 3 and Figure 6).

ZOOPLANKTON DATA

- Relevance: productivity, biodiversity, species of interest, habitat (in relative order).
- Sampling: AZMP surveys, groundfish surveys, pelagic net tows, 400 taxa.
- Spatial coverage: 2367 net deployments, 126 missions.
- Temporal coverage: 1999 to 2014, annual surveys.

- Source code: https://github.com/jae0/aegis/

Number of net deployments for each month is shown in Figure 7 and the corresponding spatial distribution of the net deployments are shown in Figure 8. Note that most of the net data were collected in July during summer groundfish survey missions and in April and October on AZMP spring and fall missions, while winter months contain mostly fixed station data (Halifax 2 and Prince 5). Abundance patterns are found in Figure 9. The QA/QC issues are identified in Appendix 1.

REMOTE SENSING DATA

Ocean Colour

- Relevance: productivity, habitat, biodiversity and species of interest (in relative order).
- Sampling: MODIS.
- Spatial coverage: 39°N to 62.5°N and 42°W to 71°W, resolution of 1.5 km.
- Temporal coverage: August 2002 to March 2015, 610 quarter-monthly (8-day) composite images.
- Source code: https://github.com/jae0/aegis/

Ocean colour refers to the spectral distribution of light emerging from the ocean that carries information about water constituents, particularly about biologically useful chlorophyll concentration in the surface layer. When measured from satellites, it provides unique synoptic view of chlorophyll spatial distribution over large areas of the ocean on a daily time scale.

The nominal uncertainty of chlorophyll products derived from ocean colour satellites is 35%, with better agreement with *in-situ* chlorophyll for the open ocean (Moore et al. 2008), while overestimation is often observed in the coastal ocean (Darecki and Stramski 2004). This is due to the inability of the algorithms to distinguish chlorophyll from suspended particulate matter and colored dissolved organic matter often present in the coastal waters as, for example, in the Bay of Fundy and Northumberland Strait.

Ocean colour satellite data for this study was provided by the Remote Sensing Unit (RSU) from the Bedford Institute of Oceanography (BIO) as 8-day composite chlorophyll images, which are routinely produced by the unit for the AZMP. The dataset was created using the Moderate Resolution Imaging Spectroradiometer (MODIS-Aqua) data, where the chlorophyll-a values are based on the 2012 reprocessing carried by the National Aeronautics and Space Administration (NASA) using OC3 chlorophyll algorithm. Composite images were created from daily Level-2 MODIS-Aqua files downloaded from NASA by averaging valid chlorophyll-a values for each pixel using all available daily images within that time period (Caverhill et al. 2015; Feldman and McClain 2015). The dataset is comprised of years 2002 to 2015 and area 39°N to 62.5°N and 42°W to 71°W, with spatial resolution of about 1.5 km per pixel.

Even though there is ocean color data available before the MODIS launch, it was decided to limit our dataset to a single sensor to avoid potential biases between the sensors. Due to the frequent cloud coverage of the Northwest Atlantic, it was decided to use 8-day composite images as daily images would not provide a sufficient number of valid pixels.

The values of chlorophyll-a pixels within St. Anns Bank polygon were extracted from each 8-day composite image and average chlorophyll-a concentration was computed for the polygon. The time series for the polygon and the associated climatology that was computed from time series data show characteristic spring blooms in March and April, with varying intensity and timing

throughout the years (Figures 10 and 11). An example of MODIS semi-monthly chlorophyll-a products showing spring bloom progression in the St. Anns Bank area in 2012 is shown on Figure 12.

Primary Production

- Relevance: productivity, habitat, biodiversity and species of interest (in relative order).
- Sampling: MODIS.
- Spatial coverage: 39°N to 62.5°N and 42°W to 71°W, resolution of 1.5 km.
- Temporal coverage: July 2002 to December 2014, 150 monthly images.
- Source code: https://github.com/jae0/aegis/

Marine primary production plays an important role in biogeochemical cycles, in food web dynamics, and in marine fisheries. It may be defined as the amount of organic material (or organic carbon) produced per unit area (or volume) per unit time by photosynthetic plants, predominately by phytoplankton.

Primary production of the ocean on synoptic scale is estimated by models that use satellite data (Sea Surface Temperature (SST), ocean colour chlorophyll, and available light estimates at the surface), shipborne *in-situ* information on the vertical distribution of phytoplankton in the water column, and the phytoplanktons photosynthetic response to light.

Monthly primary production data were provided by the Remote Sensing Unit at BIO that routinely generates production maps for the Northwest Atlantic as part of the AZMP. The general approach for the production computation is described in Platt et al. (2008) and employs chlorophyll and light estimates from MODIS, SST produced by the unit, and DFO's archive of shipborne measured parameters. This particular production algorithm has been validated with *in-situ* measured production (Platt and Sathyendranath 1988) and also has performed very well in global comparisons (Carr et al. 2006).

Primary production for each pixel within St. Anns Bank polygon was extracted from the monthly images, and average production was computed for the polygon. The time series for the polygon and the associated monthly climatology are showing peaks in primary production in spring and summer, with varying intensity and timing throughout the years (Figure 13 and Figure 14).

Sea Surface Temperature

- Relevance: productivity, habitat, biodiversity and species of interest (in relative order).
- Sampling: AVHRR.
- Spatial coverage: 39°N to 62.5°N and 42°W to 71°W, resolution of 1.5 km.
- Temporal coverage: December 1997 to March 2015, 845 8-day composite images.
- Source code: https://github.com/jae0/aegis/

Sea Surface Temperature (SST) from space was estimated using infrared channels of the Advanced Very High Resolution Radiometer (AVHRR) on board the polar-orbiting satellites.

The SST data for this study was provided by the Remote Sensing Unit from the BIO that has been downlinking AVHRR data from NOAA satellites since 1997 on an L-band satellite receiver that resides on the roof of the BIO. They routinely process the received data and supplement it with data stream from the AVHRR onboard the European satellites. Composite SST images of

different periods are operationally produced as part of the AZMP. Here we used 8-day composite images with the same spatial coverage and spatial resolution as the ocean colour chlorophyll data.

The SST pixels within St. Anns Bank polygon were extracted from each 8-day composite image and average SST was computed for the polygon. The time series for the polygon and the associated climatology that was computed from time series data are shown on Figures 15 and 16. An example of semi-monthly SST products corresponding to the spring bloom progression in the St. Anns Bank area in 2012 is shown in Figure 17.

BOTTOM TEMPERATURES

- Relevance: productivity, habitat, biodiversity and species of interest.
- Sampling: Groundfish survey, Snow Crab survey, AZMP profiles.
- Spatial coverage: full extent, varied sampling.
- Temporal coverage: 1950 - present (more historical data present but coverage is variable).
- Source code: https://github.com/jae0/aegis/

Numerous data sources have been compiled by Ocean Sciences Division, DFO. The data were QA/QC controlled and then modeled in a two-part process, temporal (first order harmonic analysis) and then spatial interpolation as indicated in the Methods (Figure 18).

DEMERSAL FISH AND MACRO-INVERTEBRATES

- Relevance: productivity, habitat, biodiversity and species of interest.
- Sampling: Groundfish survey, Snow Crab survey.
- Spatial coverage.
  - Groundfish: full extent, random stratified, variable number of stations.
  - Snow Crab: Colder water environment, geostatistical grids of approximately 10 minutes and approximately 400 stations.
- Temporal coverage.
  - Groundfish: 2000 - present (started in 1970, but consistent sampling since 2000).
  - Snow Crab: 2005 - present (started in 1996, but consistent sampling since 2005).
- Source code:
  - Groundfish: https://github.com/jae0/aegis/
  - Snow Crab: https://github.com/jae0/bio.snowcrab/

Groundfish Survey

The Groundfish survey (Figure 19, left) utilizes a Western II-A Otter Trawl net with a wingspread that is **assumed** to be 12.5 m and a target distance of 1.75 nautical miles (3.24 km) and/or a 20-30 min tow. This net was used from 1982 to the present. Prior to this period, a Yankee 36 ft trawl was used with unmeasured net configuration data. It operates night and day. Sampling occurrence as a function of time and season are shown in Figure 19 (right). The consistent identification of invertebrates in this survey began in approximately the year 2000. All species assemblage analyses will use data from the post 2000 period.

Net Mensuration

Sensors measuring trawl net configuration and state are ubiquitous in modern surveys and commercial fishing practices. In the Snow Crab survey, net configuration has been monitored and used to determine swept area manually (since 1996) and also with an automated procedure (since 2004). Unfortunately, in the groundfish survey, this information is ignored, even though the survey series is a major source of information for many stock assessments. Net configuration data have been collected in the groundfish surveys sporadically since 2004 (Figure 20). However, swept area estimates have never been directly computed. Instead, the catch data is used almost invariably with the assumption that each tow is equivalent in swept area (a "standard tow"). Alternatively, it has also been used by some assessments by "adjusting" catch data by the linear distance from "start" and "end" times and locations and so implicitly assuming the net configuration to be a constant (Don Clark, personal communication). Both approaches are problematic for the reasons identified below.

To address these important and incorrect assumptions, algorithms were developed to automatically determine lift off and touch down times, locations and net width (Munden, J., and J.S. Choi. (in prep) Calculating Swept Area for the Maritimes Region Trawl Survey). Based upon random visual inspection, the skill was determined to be reasonable, with >90% of the cases having estimates within 15 seconds of visual determination of touch down/lift off locations. Where bias was observed, this was mostly to underestimate total contact time due to an over-smoothing of the lift off or touch down profiles.

From this re-analysis, the actual time and distance of bottom contact was found to range from approximately 10 to 40 minutes and distances from 1.75 to 6 km. Historical studies assumed a "standard tow" of 3.24 km in length. Even when compared to the "length" of a tow determined from positions recorded of "start" and "stop", times or locations were frequently in error relative to actual locations of net touch down and lift-off determined from the Global Positioning System (GPS) information (Figure 21).

Net structure also varies along tows and between tows as it encounters differing substrate, bathymetric and hydrodynamic conditions and vessel speeds, currents, surface sea state, and net fullness/filtration efficiency due to contact with rocks, boulders and mud. Assuming net width to be a constant at 12.5 m is, therefore, problematic (Figures 22 and 23).

When the variable nature of the length and width of survey tracks are both accounted for, the potential error in swept area estimates are evidently large (Figure 24). Indeed, the range in variation of swept area was approximately the same in magnitude as the swept area of a standard tow. This means that an unnecessary and large "observation error", potentially as large in magnitude as the magnitude of the catch in a set, may be needlessly introduced to survey indices. Further, swept area estimates based upon standard tows were also biased down relative to estimates based upon net mensuration and actual tow tracks, meaning that there is a high probability of over-estimating catch densities.

Unfortunately, net mensuration data is still not consistently recorded nor used in the groundfish surveys (Figure 20). As a result, it is not possible to satisfactorily estimate swept area for all historical sets. Statistical methods of recalibration were used to impute swept area in these latter sets (Figure 24), using GAM-based estimates based on relationships with location, depth and salinity (R^2 ranged from 40 to 60%, depending upon availability of covariates). However, due to issues with a significant bias detected in wingspread sensors since 2013 (Figure 23), this approach **cannot** be extended for the period post-2013.

To conclude this section, the observation error (uncertainty) associated with this data series, used in so many research programs, is high and biased high. Removal of these errors by a

coherent representation of net configuration is simple to address and a major data gap that needs to be addressed before this data series can be used quantitatively.

Snow Crab Survey

The Snow Crab survey uses a Bigouden Nephrops trawl (Figure 19), a net originally designed to dig into soft sediments for the capture of lobsters in Europe (headline of 20 m, 27.3 m foot rope mounted with a 3.2 m long 8 mm chain, with a mesh size of 80 mm in the wings and 60 mm in the belly and 40 mm in the cod-end). Tows were conducted for approximately 5 minutes in duration with duration of bottom contact being monitored by Netmind and Seabird sensors. The width of the mouth of the net was also monitored with Netmind sensors. The ship speed was maintained at approximately 2 knots. The warp length was approximately 3 times the depth. Positional information, as well as, water temperature measurements, was collected using a global positioning system and Minilog and Seabird data recorders. The surface area swept by the net was calculated from swept distance and net width information.

Supplemental SAB Stations

The 2015 Snow Crab trawl survey increased sampling in the St. Anns Bank area to provide additional information about the marine macro-fauna. Fourteen stations (14) in, and adjacent to, the proposed MPA location were included in this additional sampling. These locations were close to previous Snow Crab survey stations and represent varied depths, bottom-types and habitats. The species composition of the catch at these stations varied greatly, as expected with differences in depth and bottom type. The sampling at these stations included:

- all catch identified to species level;
- all species counted and weighed to a tenth of a kilogram;
- all finfish and crab species measured and weighed individually; and
- stomach samples taken from finfish for diet studies.

An overview (in Google Earth format) of the latest catch and sampling at these stations can be found at: http://www.enssnowcrab.com/mpa/mpatows.kmz.

FISHERIES ACTIVITY

- Relevance: productivity, habitat, biodiversity and species of interest.
- Sampling: MARFIS and ZIFF.
- Spatial coverage: full extent.
- Temporal coverage: 1999 – present.
- Source code:
  - Net Mensuration: https://github.com/jae0/netmensuration
  - Data Wrangling: https://github.com/Maritimes/Mar.datawrangling/

Commercial-fishing activities can modify the habitat and ecosystem and contribute to changes in the structure and functioning of exploited marine communities. Fishing impacts can be direct, such as the reduction of targeted and non-targeted species, as well as truncations in age and size distributions. Other direct effects due to fishing activities include habitat alterations and substrate modifications through interactions with fishing gear. Fishing can also cause indirect impacts via changes in foodweb structure within an ecosystem.

Direct impacts of commercial fishing can be measured using data from the Marine Fish (MARFIS) database that provides information on commercial-fishing activities. For most fisheries, the fishing position, gear type, catch per unit effort, and estimated weight of catch by species information is available from the database. The MARFIS database details information for all fishing trips where a landing is reported within the DFO Maritimes Region and includes data from 2002 through 2015. The exploitation of marine species and entanglement threat to cetaceans and sea turtles will be quantified from data derived from the MARFIS database.

Trawling and dredging disturbances to the sea floor will require different estimation techniques. Vessel Monitoring System (VMS) point locations have been used to estimate fishing-effort distributions (e.g., Lee et al. 2010) and to estimate impacts on the seabed (Gerritsen et al. 2013). Similar techniques can be developed within R to estimate the impacts to benthos from trawling and dredging activities within the St Anns Bank area.

The St. Anns Bank Area of Interest has four zones within it with various levels of fishing restrictions (Figure 1). Commercial fishing is restricted in Zone 1, the largest area, with the exception of the seal harvest. The MPA requires monitoring to ensure that fishers are complying with these regulations. Monitoring could be done through a variety of techniques and data sources, including data reported in the MARFIS database and VMS data that allow the direct monitoring of fishing activities. Automatic Identification System (AIS) data may also be used to monitoring fishing activities if the vessel is large enough to require AIS (≥ 300 gross registered tonnes) or if a fishing vessel has voluntarily installed an AIS system onboard.

MARFIS Data Extraction

Prorated landings for all species from 2002 onwards were extracted from MARFIS. The proration process distributes the actual reported weights across the reported efforts as identified within the fishers' logs.

In addition to the landings, we also included several other forms of catch so as to better reflect the removal of biomass. These catches were identified by their CATCH USAGECODE and include biomass used as bait or discarded (sometimes identified as dead). Live discards were not included. These catches were self-reported in a variety of units, so they have been converted to kilograms as necessary to match the logged landings.

Most log records included the spatial location of the catch, and some catches have multiple sets of coordinates available within the table MARFISSCI, LOGEFRTSTDINFOID, ENTLATITUDE and ENTLONGITUDE are physically entered into the logbook by the fisher, and they were used preferentially over DETLATITUDE and DETLONGITUDE, which are determined from other sources (like Loran-C).

Many logs have no usable coordinates since they are either left blank or are clearly incorrect (i.e. on land). Rather than discarding this data, we still extracted it and attempted to account for this biomass in the next section.

MARFIS Data Quality Control and Aggregation

Quality Control (QC) occurs in 2 stages and is quite simple. First, all records without coordinates are identified and retained, but they are removed from the main dataset. Next, all remaining data are compared against a high resolution coastline (the same as is shown in Figure 2), and those points falling on land are identified and retained but removed from the main dataset.

The remaining data are considered good and are aggregated. The aggregation level is user-defined. A scale of 3 minutes is used by default since it is an even division of a degree, with no

potential for rounding errors. The aggregation process outputs a single record with a single position for all of the catch in the area.

Following aggregation, the proportion of the total catch attributable to each cell is calculated. The data that failed the QC tests are then summed into a single value, representing the total catch that cannot be positioned. These data are then added to all of the cells in the same proportion as was calculated in the previous step.

For example, one cell might have a total catch of 3269.7 kg, and this cell represents 0.002167 of the total catch. If there are 5954.1 kgs of un-positioned data, then the corrected value for the weight attributed to this cell would be calculated as: 3269.7 kg + (55954.1 kg * 0.002167) = 3390.9 kg.

An example of the annually aggregated (2010) reported commercial catches for sea scallops (*Placopecten magellanicus*) is presented in Figure 25. Nominal catches ranged to 14,073.8 kg in Bay of Fundy, Georges Bank, and the Scotian Shelf.

Similarly, an example of annually aggregated (2011) reported commercial catches for Atlantic Halibut (*Hippoglossus hippoglossus*) is shown in Figure 26. Nominal catches ranged to approximately 9626.9 kg in the same area.

VESSEL ACTIVITY

- Relevance: habitat, biodiversity and species of interest.
- Sampling: AIS.
- Spatial coverage: Global for satellite AIS, coastal (approximately 100 km) for Canadian Coast Guard terrestrial AIS network.
- Temporal coverage: 2013 – present.
- Source code: https://github.com/jae0/aegis/

Commercial shipping can have various direct and indirect effects on an ecosystem. Direct effects including the contamination of the ecosystem from the discharge of contaminates, radiated underwater noise, the introduction of aquatic invasive species, and vessel-strike risk to marine mammals and sea turtles. Spatial-temporal data on vessel traffic is needed to determine the probability and/or magnitude of these effects on ecosystems. Such information is available through AIS data.

The International Maritime Organization (IMO) requires AIS transponders on all international vessels ≥ 300 gross tonnage and all passenger vessels. Many studies have used AIS data to examine risk of lethal vessel collisions to large whales (e.g., Vanderlaan and Taggart 2009; Wiley et al. 2011; Redfern et al. 2013; Guzman et al. 2013) or to assess and monitor ship noise and assess the impact on marine mammals (Hatch et al. 2008; McKenna et al. 2012; Hatch et al. 2012; Merchant et al. 2014). Similar exercises can be undertaken in the St. Anns Bank area with AIS data.

Fisheries and Oceans Canada (DFO) has access to two different sources of AIS data. The first is from the Canadian Coast Guard (CCG) terrestrial system that was developed to track and monitoring coastal shipping and provides a real-time, continuous stream of AIS vessel positions. Archived historical data from this system is available for January 2012 through December 2015, and data from 2016 are currently streaming and archiving to a server within DFO. Decoding routines have been developed using native R methods for these data. Both sources of data provide dynamic and static data, where the dynamic data includes information on vessel

identity, speed, and location, and static data includes information vessel identity, name, size, and type.

The CCG terrestrial system have 21 AIS coastal receiving stations in the Maritime region and 19 AIS coastal receiving stations in Newfoundland and Labrador. These receiving stations have limited range for detecting vessels (Figure 27) as AIS transmission detectability are primarily a function of the receiving tower height above sea level and the height of the AIS antenna on the transmitting vessel. AIS data is transmitted via Very High Frequency (VHF) marine radio on two channels (161.9765 and 162.025 MHz). Based on the height of the associated towers and a vessel with an AIS antenna 100 m high, line of sight calculations for VHF provide a reception range of 57 to 113 m in and around St. Anns Bank (Figure 28). However, there are several other factors that will contribute to transmission range, including weather conditions. Simard et al. (2014) estimated that coastal antennas within this network generally provide a reception range of 100 km (Figure 29). In either case, the terrestrial network is insufficient to monitor vessels across the entire AOI and just north of the AOI. These data can be combined with satellite AIS data.

The satellite AIS data are available globally for the years 2013, 2014, and 2015 with on-going data collection for 2016. Although satellite AIS data coverage is global, data are limited temporally as large sections of vessel transits are unavailable due to a limited number of satellites (n = 8) and their orbital paths (see Figure 30). Spatial interpolation must be completed to fill in missing data. Spatial interpolation is achieved using an A* function (Hart et al. 1968) that estimates the minimum cost to get from one point to another based on a cost map. Using seasonally aggregated annual density distributions of satellite AIS data for the years 2013 through 2015 (Figure 31), cost maps were estimated (Figure 32). Grid resolution for this analysis was initially set to 0.01 degrees and, within each grid square, the number of unique vessels identified by the vessel's Maritime Mobile Service Identity (MMSI) number was counted daily and summed through time. Cost maps were estimated quarterly. Two different cost maps were developed for the St. Anns Bank area to interpolate vessel transits north of Cape Breton into and out of the Gulf of St. Lawrence. Interpolation was heavily influenced by the ferries transiting between Cape Breton and Newfoundland and, therefore, a cost map was developed without the data derived from these ferries. A bathymetric restriction can also be built into the cost maps.

DATA GAPS

Feeding Relationships – Stomach Database

Bottom trawl surveys have been conducted by DFO on the Scotian Shelf annuallt since 1970 using a stratified random design. Sampling protocols changed in the late 1990s with the focus changing from commercially important finfish species to more comprehensive ecosystem monitoring that included the sampling of macro invertebrates (Tremblay et al. 2007). Stomach contents samples were collected from finfish using a length-stratified sampling protocol. Prey were quantified by weight and number, and they are often identified to the genus or family level, or to the species level when possible.

For the purpose of determining any change in the diet of finfish, pre- and post-implementation of the MPA on St. Anns Bank, or if there were differences within the area compared to other areas on the Scotian Shelf, we explored the stomach database to determine if these dietary differences could be described and detected. Within the database, 54% of the prey number observations were missing. Due to the large interannual variation in prey weights, estimating the prey number consistently from non-missing data where both the prey number and weight was available was determined to be impracticable and unreliable. Due to the sampling stratification

both by depth and length classes, it was further determined that there would be insufficient samples available to reach the asymptote of prey species accumulation curves (Cook and Bundy 2010) and total diet composition could not be detected. Prey species identified in the stomach samples could be used for quantifying biodiversity and species richness (Cook and Bundy 2012) for the proposed MPA and comparing it to similar ecosystem or pre- and post-implementation.

Other Ecosystem Metrics

On the side of ecosystem characterization, data gaps in the following are evident: pelagic fish (small and large bodied) and invertebrates (e.g., squid, jellyfish), substrate characterisation via multibeam surveys, marine mammals, reptiles, birds and genetic diversity. They are gaps in that they are expensive and/or difficult to monitor and/or contain information that is not readily available at present.

Other Human Usage Metrics

A large number of variables and ecosystem descriptors are being ignored. In particular, these include human influences such as seismic activity, pollution, ballast water, etc. They may be addressed once the basic biological features have been fully addressed.

METHODS

All methods have been implemented in R, an open-sourced programming environment. The methods are shared via GitHub using the **git** revisioning system. These architectural choices were adopted to enhance the transparency and ease of sharing and collaborating with all interested parties. It is structured such that any additional data series can be easily added to the system to permit adaptive change. In this way, the approaches developed represent a true structural **framework** in which to further develop methods and approaches.

The main methods used/developed in this report will be described in this section.

BIODIVERSITY AND TAXONOMIC RICHNESS

Biodiversity is seemingly a simple concept that is, in fact, fundamentally complex. This is because it ranges in focus from genetic and phenotypic variations within a local population, to breeding populations, to biome or even larger scaled genetic and phylogenetic and community variability, both in terms of their number and relative dominance. Any and all of these aspects of biodiversity can be estimated. However, it is the number of unique kinds of organisms found in a given location (commonly called taxonomic richness) that is most readily quantified and monitored.

Taxonomic richness is known to increase asymptotically with sampling intensity. As such, a statistical correction ("rarefaction") for spatial and temporal sampling intensity must be applied to be meaningfully comparable across locations and time. Specifically, a simple regression model was used to predict an expected richness *R* at a standard surface area and time depth:

$$R \sim \text{Lognormal}((\beta + \alpha_s \log(\text{SA}) + \alpha_t \log(\text{TS})), \tau)$$

The other terms are β a constant, SA surface area (ranging from 1 to 50 km, radial length scale), TS, the number of years entering into the count (ranging from 0 to 5 years) and τ is a lognormal error. The autocorrelation in SA and TS are ignored for the present but will eventually be modeled as well via a Poisson process.

The intent is to model the spatial/temporal patterns and then integrate them in a risk-based, probability model to permit formal statements of risk and probability of exceeding thresholds.

PRODUCTIVITY

Total system standing biomass is generally used as a proxy for productivity. They are not the same; however, they will be used to describe aggregate abundance of: various categories of organisms such as total bottom biomass, macroinvertebrates, zoopankton, phytoplanton, chlorophyll-a, etc.

To estimate true production, a modeled approach is necessary. These indices can then be coupled with spatially explicit total landings to estimate the biomass and secondary production associated with the biota and fishery exploitation/footprint.

The intent is, therefore, to model the spatial/temporal patterns and then integrate them in a risk-based approach to permit formal statements of risk and probability of exceeding thresholds and perhaps even estimate net production.

HABITAT

The basic Hutchinsonian notion of "ecological niche" is closely tied to our current understanding of "habitat". It is a multi-dimensional concept in that it incorporates an undefined set of environmental variables and the associated biological constraints/specialisations/requirements (e.g., nutrients, thermal, oxygen, pH, etc.) pertinent to an organism of interest.

Two notions of habitat can be discriminated, depending upon outlook:

- Functional (H_f) – make increasing more precise habitat definitions by adding more environmental and biological factors for increasingly more precise categories of organisms.
- Integrative (H_i) – the biota living in a given time and location represent a full integration of all relevant environmental and biological factors at their proper space time scales and so, in effect characterises the full system-level concept of "habitat space".

Functional-habitat Modeling

A utilitarian way of describing the **Functional-habitat** (H_f) space of an organism is to examine the presence-absence or relative abundance of organisms as a function of environmental gradients and biological/life history constraints. From such information, the likelihood of a given location to be potential habitat for an organism of interest can be derived. The most robust method is to develop a probability model under the assumption that the presence or absence of an organism is a Bernoulli process. This can be readily parameterised using standard Generalized Linear Models. However, as environmental constraints are almost always modal in influence given a wide enough environmental gradient, a nonlinear model is more useful. Generalized Additive Models and Stochastic Partial Differential Equation Models are two methods that can deal with these environmental constraints in a simple and efficient manner (Choi 2010; Appendix 3).

The utility of such an approach is most relevant for organisms with highly specific habitat requirements. They are used in this framework. The intent is to develop such Functional-habitat models for key species of interest: wolffish, Cod, etc., to assess changes in their available "habitat". Examples are provided from those derived in the Snow Crab assessment (see Results). Though this Functional-habitat concept itself does not exclude species interactions, in actual practice, they are generally ignored as they make the statistical estimation impossibly over-parameterized (but see Choi et al. 2012, for one possible solution). Further, as there will

always be factors that are either poorly known, poorly sampled, or poorly parameterized, (e.g., dissolved oxygen, pH, redox, bacteria, jellyfish, squid, pollution, substrate type, etc.), these models will always necessarily be incomplete.

It is relatively straightforward to model the spatial/temporal patterns and then "integrate" them in a risk-based approach to permit more formal statements of risk and probability of exceeding thresholds.

Integral Habitat – Whole System Level

While the Functional-habitat concept is interesting and pragmatic, it is decidedly a reductionistic perspective. The monitoring and assessment requirements for an MPA also demands a whole system (phenomenological) perspective. The *assumption* we make is that **the relative abundance of organisms found in a given location and time defines and mirrors the kind of habitat in which they live**. Sessile organisms that require high flow environments and associated biota tend to exist and flourish with a given group of other organisms similarly adapted, and they are different from those that require cold waters and minimal water flow, etc.

Thus, if we can quantify the observed species composition in a given location and time, we would, in effect, be describing the habitat. We will define this as **Integral-habitat** (H_i): species assemblage information that directly reflects all biological and environmental interactions simultaneously, both measured and unmeasured, and some too fleeting to be measurable.

Fortunately, these associations are readily quantified using multivariate methods of data ordination. Here we focus upon Principal Components Analysis, which focuses upon an eigenanalysis of correlational structure of the species assemblages. An example derived from the Snow Crab assessment is provided in the Results.

The intent is to model the spatial/temporal patterns and then integrate them in a risk-based approach to permit formal statements of risk and probability of exceeding thresholds.

CONNECTIVITY: SPACE AND TIME SCALES

Spatial Scale

Marine Protected Areas exist in a spatial context. The characteristic spatial scale of productivity, diversity and habitat found in the MPA will determine which processes will be relevant to these aspects of an MPA. If the spatial variations in the productivity of a species of interest is small relative to the size of an MPA, the chances of the MPA having an influence upon the species is enhanced. This is usually the case when short-range processes dominate (e.g., less mobile species, weakly dispersing, low currents, habitat heterogeneity at small scales). If, however, the spatial scale is larger than the MPA, then it would mean that broader/larger processes were influencing the productivity of the species (e.g., higher mobility or dispersal processes/current, and stronger spatial connectivity, habitat heterogeneity at larger scales) – resulting in a lower likelihood of the MPA having an influence upon the species or components of interest.

A second important factor is the relationship of the characteristic spatial scale to monitoring. As organisms exist at a given spatial scale in a given area, a sampling/monitoring protocol must reference/address these spatial scales. For example, when a spatial feature (e.g., biodiversity) demonstrates short characteristic spatial scales (i.e., a lot of spatial structure at smaller scales), any sampling approach must respect this and similarly operate at such shorter scales or even smaller, if one is to be able to resolve the patterns and describe properly the subject of interest. Similarly, if a feature (e.g., biodiversity) is long-ranged and one wishes to resolve the patterns properly, then a sampling protocol must be similarly long-ranged to resolve the pattern. A

sampling program much smaller than the characteristic spatial scale would be beneficial, but the accrued benefits relative to cost of sampling would be rapidly diminishing. In that time, effort and resources requirements generally increase more rapidly than any benefit, (e.g., in the simplest case, if one is looking only naively at standard error as a measure of benefit, then it would increase asymptotically with increased effort with a power of $-1/2$.

For these fundamental reasons, defining the spatial scale of a given observation or process is imperative for the development of any assessment or monitoring of MPAs. To this end, we represent any spatially explicit observation as $Y(\mathbf{s})$, which are measured in a coordinate space $\{\mathbf{s} \in S \in \Re^d\}$ and domain S of dimensionality d. In this framework, we will mainly focus upon the case of $d = 2$ spatial dimensions (e.g., longitude and latitude or northing and easting). The observations $Y(\mathbf{s})$ are assumed to be realizations of a **spatial stochastic process**, y, that is, some latent, unobservable but real stochastic generative function. These are also known as (spatial) "Random Fields" in the literature. The manner in which the variability of y changes as a function of distance, $h = \| \mathbf{s} - \mathbf{s}' \|$, is known as the spatial autocorrelation function. This spatial dependence is highly informative in that it defines how the similarity of observations changes with distance and so ultimately defines **spatial scale**.

The spatial model is succinctly expressed as a regression model of a stochastic process (Banerjee et al. 2014):

$$Y(\mathbf{s}) = \mu(\mathbf{s}) + e(\mathbf{s})$$

where, the observations $Y(\mathbf{s})$ are a function of some mean process $\mu(\mathbf{s})$, and a residual error process $e(\mathbf{s})$. The latter are further defined as:

$$\begin{aligned} \mu(\mathbf{s}) &= x(\mathbf{s})^T \beta \\ e(\mathbf{s}) &= \omega(\mathbf{s}) + \varepsilon(\mathbf{s}) \end{aligned}$$

where $x(\mathbf{s})$ are spatially referenced predictors with associated parameters β; and the residual error process is decomposed into spatial $\omega(\mathbf{s})$ and nonspatial $\varepsilon(\mathbf{s})$ components. The latter is also known as "nugget" error in geostatistics and represents error associated with measurement and/or microscale variability/processes.

The error structures are usually assumed to be the following:

$$\begin{aligned} \varepsilon(\mathbf{s}) &\sim \mathrm{N}(0, \tau^2) \\ \omega(\mathbf{s}) &\sim \mathrm{GP}(0, C(\mathbf{s}, \mathbf{s}'; \boldsymbol{\theta})) \\ \mathbf{Y} &\sim \mathrm{MVN}(\boldsymbol{\mu}, \boldsymbol{\Sigma}). \end{aligned}$$

The nonspatial error is assumed normal with mean 0 and standard deviation τ. The spatial error is assumed to follow a Gaussian Process with mean 0 and covariance $C(\mathbf{s}, \mathbf{s}'; \boldsymbol{\theta})$, that is, a *spatial covariance function* with parameters $\boldsymbol{\theta}$. A multivariate normal likelihood is usually assumed for the observations $\mathbf{Y} = (Y(\mathbf{s}_1), \ldots, Y(\mathbf{s}_n))^T$, with mean $\boldsymbol{\mu} = \mathbf{X}\boldsymbol{\beta}$ and covariance $\boldsymbol{\Sigma} = \left[C(\mathbf{s}_i, \mathbf{s}_j; \theta)\right]_{i,j=1}^{n} + \tau^2 I_n$. The matrix of regressors is $\mathbf{X} = [\mathbf{x}(\mathbf{s}_i)^T]_{i=1}^{n}$ and I_n is an identity matrix of size n.

The spatial covariance function $C(h) = C(\mathbf{s}, \mathbf{s}')$ expresses the tendency of observations closer together to be more similar to each other than those further away; $h = \| \mathbf{s} - \mathbf{s}' \|$ is the distance separating observations. Historically, a number of different forms have been used. The most frequently used forms include (for $h > 0$):

$$
\begin{aligned}
C(h)_{\text{Spherical}} &= \begin{cases} \sigma^2(1 - \frac{3}{2}h/\phi + \frac{1}{2}(h/\phi)^3); & 0 < h <= \phi \\ 0; & h > \phi \end{cases} \\
C(h)_{\text{Exponential}} &= \sigma^2(\exp(-h/\phi)) \\
C(h)_{\text{Gaussian}} &= \sigma^2(\exp(-(h/\phi)^2)) \\
C(h)_{\text{Powered exponential}} &= \sigma^2(\exp(-|h/\phi|^p)) \\
C(h)_{\text{Matérn}} &= \sigma^2 \frac{1}{2^{\nu-1}\Gamma(\nu)} (\sqrt{2\nu}h/\phi)^\nu \, K_\nu(\sqrt{2\nu}h/\phi).
\end{aligned}
$$

At zero distance, $C(0) = Cov(Y(s), Y(s)) = Var(Y(s)) = \tau^2 + \sigma^2$ (*i.e.*, global variance), where τ is the nonspatial error, σ is the spatial error, and $\theta = \{\phi, \nu, p, \ldots\}$ are function-specific parameters including ϕ the *range* parameter. $\Gamma(\cdot)$ is the Gamma function and $K_\nu(\cdot)$ is the Bessel function of the second kind with smoothness ν. The latter, Matérn covariance function is frequently used as the shape of this function is more flexible (Figure 33), albeit at the cost of an additional parameter (Appendix 2).

The semivariance, more commonly used in geostatistics, is the covariance reflected on the horizontal axis of the global variance: $\gamma(h) = C(0) - C(h) = \frac{1}{2}\,\mathrm{Var}[Y(\mathbf{s}) - Y(\mathbf{s}')]$.

The **spatial autocorrelation function** is defined as the covariance function scaled by the global variance: $\rho(h) = C(h)/C(0)$. For the purposes of this framework, we will define the **spatial scale** to be the distance at which the spatial autocorrelation decreases asymptotically to $\rho(x) \rightarrow 0.05$ ("practical" range). This will be determined in modeled form where possible and, when it is not possible, an empirical estimate will be made derived from the empirical semivariogram. We focus upon spatial patterns larger than 1 km in resolution and smaller than the size of study domain, the "Scotian Shelf Ecosystem" (SSE).

Temporal Scale

Marine Protected Areas also exist in a dynamic frame. As such, similar to the above spatial considerations, there also exists some characteristic temporal scale upon which an MPA and its subcomponents operate. If the overall temporal variations of the biota and environment is small relative to the overall life of an MPA, the chances of the MPA having an influence upon the species is enhanced. Presumably, the longevity of MPAs will be long lasting and so will guarantee some influence, however small that may be; an effect that would be enhanced if the subject is shorter-ranged in spatial scales.

Again, similar to the spatial scale case, this also has a simple and obvious implication in terms of monitoring and assessment. Short-range variations require higher sampling effort to resolve/understand the issues and vice-versa.

As the temporal scale is an informative metric for monitoring and assessment of an MPA, we must be precise in its definition. Similar to the spatial case, we focus upon how the correlation and variability of some quantity changes with greater difference in time. The analogue to the semivariogram in a time series context is known as a **cumulative periodogram**.

A periodogram expresses the amount of variance found at different wavelengths (ω). It is a discrete sample estimate of the continuous concept of spectral density, $\gamma(t)$:

$$\gamma(t) = \int_{-1/2}^{1/2} e^{2\pi i \omega t} f(\omega) d\omega.$$

It is easily obtained from a Fast Fourier Transform of any arbitrary time-series and so the cumulative distribution permits a rapid identification of the time scale at which correlation drops to some arbitrary level. To be approximately comparable to the spatial scale, we define the temporal scale as the time difference by which the Cumulative Power Spectral Density increases to 95% of the total variance.

If the goal is to resolve short-term processes, then sampling must also, of necessity, be more frequent. However, similar to spatial scale issues, there is a point where there will be diminishing returns for any increase in the resolution of a temporal signal. It is the intent of this framework to operate upon timescale of 1 year or greater. Sub-annual signals, where they are available, would be used to decompose the seasonal signals from the inter-annual signals to avoid bias due to discretization errors.

Space-time Models

In reality, spatial and temporal patterns coexist and evolve. They are correlated processes and, as such, a challenge to model properly ("nonseparable" – see below). This renders the independent treatment and estimation of autocorrelation in time and space problematic. Nonetheless, new developments in computational methods are bringing such models within range of use for a framework such as this. This is primarily due to efficient methods associated with numerical modeling of Stochastic Partial Differential Equations (SPDEs), especially in spectral (Fourier) space.

Again, we follow Banerjee et al.'s (2014) development of spatio-temporal models as a simple extension of the spatial regression model. The observations, $Y(\mathbf{s},t)$ are measured in a coordinate space $(\mathbf{s},t) \in S \in \Re^d \times \Re$ in the domain S of dimensionality $d+1$. The space-time regression model can then be specified as:

$$Y(\mathbf{s},t) = \mu(\mathbf{s},t) + e(\mathbf{s},t),$$

where, $\mu(\mathbf{s},t) = x(\mathbf{s},t)^T\beta(\mathbf{s},t)$ is the mean process and $e(\mathbf{s},t)$ the residual error. The parameters β of the spatially referenced predictors x can have variable forms:

- $\beta(\mathbf{s},t)$ – varying in both time and space.
- $\beta(\mathbf{s})$ – spatially varying (fixed in time).
- $\beta(t)$ – temporally varying (and fixed in space).
- β – completely fixed (no variation in time and space).
- $\beta_s(\mathbf{s}) + \beta_t(t)$ – complex, hierarchical (mixed).

The error process can be separated into a spatiotemporally structured component ω and an unstructured component εs:

$$e(\mathbf{s},t) = \omega(\mathbf{s},t) + \varepsilon(\mathbf{s},t).$$

The *unstructured* error is usually assumed to be a white error process: $\varepsilon(\mathbf{s},t) \sim N(0,\sigma_\varepsilon^2)$. However, the manner in which the *spatiotemporally structured* error is handled is not straight-forward:

- $\omega_s(t)$ – temporal effects nested in sites (temporal evolution at each site, space is not modelled).
- $\omega_t(\mathbf{s})$ – spatial effects nested in time (spatial evolution at each time, time is not modelled).

- $\omega(\mathbf{s})\upsilon(t)$ or $\omega(\mathbf{s}) + \upsilon(t)$ – *separable* (structure in space and structure in time are independent).
- $\omega(\mathbf{s}, t)$ – non-separable (both time and space structure evolve in a nonsimple manner).

If spatial and temporal autocorrelation act independently ("separably") then:

$$\begin{aligned} \upsilon(t) &\sim \mathrm{GP}(0, C(t, t'; \boldsymbol{\theta}_t)) \\ \omega(\mathbf{s}) &\sim \mathrm{GP}(0, C(\mathbf{s}, \mathbf{s}'; \boldsymbol{\theta}_s)). \end{aligned}$$

The spatial and temporal errors are usually assumed to follow Gaussian Processes with mean 0 and covariance $C(\cdot,\cdot;\boldsymbol{\theta})$. The spatial covariance can be modelled with any spatial form such as: $C(\mathbf{s}, \mathbf{s}'; \boldsymbol{\theta}_s) = C(h)_{\text{Matérn}}$. Similarly, the temporal covariance can be formulated as any autocorrelation model such as: $C(t, t'; \boldsymbol{\theta}_t) = \sigma_t^2 \exp(-\phi_t |t - t'|)$, or if discrete in time: $\mathrm{AR}(1)\colon \upsilon(t+1) = \rho_t \upsilon(t) + \eta(t)$ with $\eta(t) \overset{iid}{\sim} N(0, \sigma_t^2)$, *etc.*

While computationally appealing, even in this simple case of "separable" models, an evaluation of the likelihood requires the inverse $\Sigma_{n\times n}^{-1}$, which happens to scale with $O(n^3)$ operations. This has been a strong bottleneck to further development of these covariance-based methods in large-scaled problems of space and space-time. Approximations have been suggested to overcome this crippling numerical problem: modeling the spatial process $\omega(s)$ with a lower dimensional process via kernel convolutions, moving averages, low rank splines/basis functions and predictive processes (projection of spatial process onto a smaller subset; Sølna and Switzer 1996, Wikle and Cressie 1999, Hung et al. 2004, Xu et al. 2005, Banerjee et al. 2014); approximating the spatial process as a Markov random field with Laplace and SPDE Approximations (Lindgren and Rue 2015); and approximating the likelihood of the spatial-temporal SPDE process with a spectral domain process (Sigrist et al. 2015).

In this framework, we focus upon Sigrist et al.'s (2015) approach due to the more realistic assumption of non-separability of space and time processes and the high computational performance of operating in spectral space. Specifically, the space-time error $\omega(\mathbf{s}, t)$ is formulated as an advection-diffusion process (SPDE):

$$\frac{\partial}{\partial t}\omega(\mathbf{s}, t) = -\mathbf{u}^T \nabla \omega(\mathbf{s}, t) + \nabla \cdot \Sigma \nabla \omega(\mathbf{s}, t) - \zeta \omega(\mathbf{s}, t) + \epsilon(\mathbf{s}, t).$$

Here, $\mathbf{s} = (x, y)^T \in \Re^2$: $\mathbf{u} = (u_x, u_y)^T$ parameterizes the drift velocity (advection); $\nabla = (\frac{\partial}{\partial x}, \frac{\partial}{\partial y})^T$ is the gradient operator; $\nabla \cdot \mathbf{F} = (\frac{\partial F_x}{\partial x}, \frac{\partial F_y}{\partial y})^T$ is the divergence operator for a given vector field $\mathbf{F} = (F_x, F_y)^T$; $\Sigma^{-1} = \frac{1}{\phi_d^2}\begin{pmatrix} \cos\alpha & \sin\alpha \\ -\gamma \cdot \sin\alpha & \gamma \cdot \cos\alpha \end{pmatrix}^T \begin{pmatrix} \cos\alpha & \sin\alpha \\ -\gamma \cdot \sin\alpha & \gamma \cdot \cos\alpha \end{pmatrix}$ parameterizes the anisotropy in diffusion via ($\gamma > 0$, $\alpha \in [0, \pi/2]$) with $\phi_d > 0$ parameterizing the diffusion range; $\zeta > 0$ parameterizing local damping; and $\epsilon(\mathbf{s}, t)$ parameterizing a Gaussian random field that accounts for source-sink processes with white noise in time and Matérn spatial covariance (aka, "innovation").

The full advection-diffusion model specification in state space form is (Sigrist et al. 2015):

$$\begin{aligned} Y(\mathbf{s}, t) &= x(\mathbf{s}, t)^T \boldsymbol{\beta} + \omega(\mathbf{s}, t) + \varepsilon(\mathbf{s}, t) \\ \omega(\mathbf{s}, t) &= \boldsymbol{\Phi}\boldsymbol{\alpha}(\mathbf{s}, t) \quad \{\text{discretized advection} - \text{diffusion process}\} \\ \alpha(\mathbf{s}, t) &= \mathbf{G}\boldsymbol{\alpha}(\mathbf{s}, t-1) + \hat{\epsilon}\,(\mathbf{s}, t) \quad \{\text{transition model}\} \\ \varepsilon(\mathbf{s}, t) &\sim N(\mathbf{0}, \tau^2 \mathbf{1}) \quad \{\text{unstructured error}\} \\ \hat{\epsilon}\,(\mathbf{s}, t) &\sim N\big(\mathbf{0}, \widehat{\mathbf{Q}}\big) \quad \{\text{innovation}\} \end{aligned}$$

where, $\boldsymbol{\alpha}(\mathbf{s},t)$ are Fourier coefficients; $\boldsymbol{\Phi} = [\boldsymbol{\phi}(\mathbf{s}_1), \ldots, \boldsymbol{\phi}(\mathbf{s}_N)]^T$ is a matrix of spatial basis functions; $\mathbf{G}$ is the transition matrix; and $\widehat{\mathbf{Q}}$ is the innovation covariance matrix (residual errors). See Appendix 3 for more details.

Once the form of the space-time model is formulated, it can be used as a predictive/interpolating method. Such interpolation is required to describe and understand the linkages between the key ecosystem attributes of productivity, biodiversity, habitat, and species of interest, as well as, to estimate the spatial and temporal scales.

We use an R-package implementation of the above space and space-time (stmv, https://github.com/jae0/stmv). The stmv library additionally permits localised, hierarchical, model-based interpolations, for a given (local) subdomain, indexed by λ. Note that μ indicates a global regressor in a linear, nonlinear or binomial functional form f, and μ_λ represents a local regressor specific to the subdomain λ. The model specifications for each data series are as follows:

- Bathymetry (pure space model):

$$\begin{aligned} Y_\lambda(\mathbf{s}) &= \omega_\lambda(\mathbf{s}) + \varepsilon_\lambda(\mathbf{s}) \\ \omega_\lambda(\mathbf{s}) &\sim \mathrm{GP}(0, C(\mathbf{s},\mathbf{s}';\boldsymbol{\theta}_\lambda)) \\ \varepsilon_\lambda(\mathbf{s}) &\sim \mathrm{N}(\mathbf{0}, \tau_\lambda(\mathbf{s})^2) \end{aligned}$$

- Substrate grainsize (space with covariates):

$$\begin{aligned} Y_\lambda(\mathbf{s}) &= \mu(\mathbf{s}) + \omega_\lambda(\mathbf{s}) + \varepsilon_\lambda(\mathbf{s}) \\ \mu(\mathbf{s}) &= f(\,\mathrm{depth}, \mathrm{slope}, \mathrm{curvature}\,) \\ \omega_\lambda(\mathbf{s}) &\sim \mathrm{GP}(0, C(\mathbf{s},\mathbf{s}';\boldsymbol{\theta}_\lambda)) \\ \varepsilon_\lambda(\mathbf{s}) &\sim \mathrm{N}(\mathbf{0}, \tau_\lambda(\mathbf{s})^2) \end{aligned}$$

- Bottom temperature (temporal effects nested in sites):

$$\begin{aligned} Y_\lambda(\mathbf{s},t) &= \mu(\mathbf{s}) + \omega_\lambda(\mathbf{s}) + \varepsilon_\lambda(\mathbf{s}) \\ \mu(\mathbf{s}) &= f(\,\mathrm{depth}\,) \\ \omega_\lambda(\mathbf{s},t) &= \boldsymbol{\Phi}_\lambda \boldsymbol{\alpha}_\lambda(\mathbf{s},t) \\ \alpha_\lambda(\mathbf{s},t) &= \mathbf{G}_\lambda \boldsymbol{\alpha}_\lambda(\mathbf{s},t-1) + \hat{\epsilon}_\lambda\,(\mathbf{s},t) \\ \varepsilon_\lambda(\mathbf{s},t) &\sim N(\mathbf{0}, \tau_\lambda^2 \mathbf{1}) \\ \hat{\epsilon}_\lambda\,(\mathbf{s},t) &\sim N(\mathbf{0}, \widehat{\mathbf{Q}}_\lambda) \end{aligned}$$

- Ecosystem indicators (including integrative habitat H_i; temporal effects nested in sites):

$$\begin{aligned} Y_\lambda(\mathbf{s},t) &= \mu(\mathbf{s}) + \mu_\lambda(\mathbf{s},t) + \omega_\lambda(\mathbf{s}) + \varepsilon_\lambda(\mathbf{s}) \\ \mu(\mathbf{s}) &= f(\,\mathrm{depth}, \mathrm{slope}, \mathrm{curvature}, \mathrm{substrate\ grainsize}\,) \\ \mu_\lambda(\mathbf{s},t) &= f_\lambda(\,\mathrm{temperature}\,) \\ \omega_\lambda(\mathbf{s},t) &= \boldsymbol{\Phi}_\lambda \boldsymbol{\alpha}_\lambda(\mathbf{s},t) \\ \alpha_\lambda(\mathbf{s},t) &= \mathbf{G}_\lambda \boldsymbol{\alpha}_\lambda(\mathbf{s},t-1) + \hat{\epsilon}_\lambda\,(\mathbf{s},t) \\ \varepsilon_\lambda(\mathbf{s},t) &\sim N(\mathbf{0}, \tau_\lambda^2 \mathbf{1}) \\ \hat{\epsilon}_\lambda\,(\mathbf{s},t) &\sim N(\mathbf{0}, \widehat{\mathbf{Q}}_\lambda) \end{aligned}$$

- Abundance and functional habitat (H_f; temporal effects nested in sites):

$$
\begin{aligned}
Y_\lambda(\mathbf{s},t) &= \mu(\mathbf{s}) + \mu_\lambda(\mathbf{s},t) + \omega_\lambda(\mathbf{s}) + \varepsilon_\lambda(\mathbf{s}) \\
\mu(\mathbf{s}) &= f(\text{ depth, slope, curvature, substrate grainsize }) \\
\mu_\lambda(\mathbf{s},t) &= f_\lambda(\text{ temperature, ecosystem indicators }) \\
\omega_\lambda(\mathbf{s},t) &= \mathbf{\Phi}_\lambda \boldsymbol{\alpha}_\lambda(\mathbf{s},t) \\
\alpha_\lambda(\mathbf{s},t) &= \mathbf{G}_\lambda \boldsymbol{\alpha}_\lambda(\mathbf{s},t-1) + \hat{\epsilon}_\lambda(\mathbf{s},t) \\
\varepsilon_\lambda(\mathbf{s},t) &\sim N(\mathbf{0}, \tau_\lambda^2 \mathbf{1}) \\
\hat{\epsilon}_\lambda(\mathbf{s},t) &\sim N(\mathbf{0}, \widehat{\mathbf{Q}}_\lambda)
\end{aligned}
$$

Tagging and Mark-recapture

A tangible way of quantifying time and space scales (connectivity) is to demonstrate movement and genetic similarity. In the latter, no effort has been made. In the former, due to synergies with the fishing industry, increased tagging efforts have been made in the vicinity of SAB. Most of the effort has been driven by industry, Ocean Tracking Network (OTN), and Emera interest in Snow Crab movement near SAB. However, acoustic tagging of other species of interest have been completed as well. In total, 80 tags were deployed: 58 Cod, 14 Atlantic Striped Wolffish, 1 Shorthorn Sculpin and 7 Snow Crab. These tags will allow us to track these species over the coming years within the MPA (through the two existing receiver lines), as well as outside the MPA with other OTN receiver lines and potentially with an OTN glider. They will help define the spatial connectivity and range of the species of interest. The intent is to develop movement models where possible and estimate spatial range directly.

Mark-recapture information for sea turtles, seals, sharks and various other species exist in the area. These data have not been examined nor are they always available and represent a data gap at present.

RISK MODELING

Risk means many things to many people. We use the term specifically in the sense of having a believable error distribution for some quantity of interest such that probabilistic inferences can be made. Once the error distributions are determined, it is simple to make probability statements related to how likely the current state is different from some previous state or arbitrary threshold.

The estimation of such error distributions requires a reliable method to propagate the errors from observations to predictions. One venerable (**deterministic**) method is to build a mechanistic model and then using approximations or simulations to determine the error distributions of interest. A second (**phenomenological**) method empirically quantifies the errors and propagates them via statistical/correlational methods. The latter is chosen in this framework as it is very general and simple to implement. The former is not chosen as no operating model of an ecosystem nor any subcomponent is known to the authors that can be said to be able to perform with sufficient skill to be able to propagate errors, let alone, magnitudes.

The proposed approach is to use the discrete form of the logistic equation for this purpose. Verhulst, Pearl and Lotka in the late 1800s and early 1900s popularized this equation, using it to describe patterns of asymptotic increase (population growth, economic growth, etc.). The model is sufficiently general that it can be readily applied to most quantities of interest that show some dynamic behaviour, such as, for example: aggregate estimates of biomass (productivity), biodiversity (biodiversity change), and habitat (habitat change). Similar techniques can be applied to the other indicators of interest and may be applied depending upon availability of time. The justification of why it can be so generally applied is developed in Appendix 4.

The discrete form the basic logistic equation is, after normalization to K, the "carrying capacity" (see Appendix 4):

$$y_t \approx r y_{t-1}(1 - y_{t-1}).$$

Perhaps the most powerful and flexible method of estimation of the parameters, $\theta = \{r, K\}$, is a state space representation where an additional observation model is added to connect observed indices O to the unobserved and (usually unobservable) real system state y. The simplest such model is a linear scaling factor, q, though again others are possible, at the cost of more complexity:

$$O_t = q y_t$$

where, $\theta = \{r, K, q\}$.

The use of a Bayesian approach to solve the above nonlinear state space problem is frequently used as it provides an opportunity to: have greater numerical stability; incorporate prior scientific knowledge in a formal manner; realistically propagate credible errors; estimate unobserved ("true") states; and simultaneously estimate model "process" errors and data "observation" errors. [Note that process errors (σ_p^2) are the uncertainties that feeds back into future states via error propagation – e.g., via the recursive form of the logistic equation (i.e., errors in y_{t+1} in the state space of y_t vs y_{t+1}). They are important if predictive risk is being assessed. Observation errors (σ_o^2) refer to the uncertainties associated with measurement and observation (i.e., measurement/data-related errors of both variables in the state space of y_t vs y_{t+1}).]

This latter ability is particularly important as parameter estimates and forecasts based on observation-only errors provide unrealistically optimistic (small and constant) error bounds. Parameter estimates and forecasts based on process-only errors expand rapidly into the future, resulting in potentially unrealistically pessimistic (large and usually growing) error bounds.

The posterior distribution of the parameters of interest, θ, conditional upon the data are estimated via MCMC (Gibbs) sampling using the JAGS platform (Plummer 2003). The JAGS model used for parameter estimation can be found at: https://github.com/jae0/stmvdev/.

ANTHROPOGENIC THREATS

Productivity, habitat and biodiversity monitoring is essential if one is to assess if MPAs are achieving their primary objectives. It is also essential to examine the anthropogenic threats in the St. Anns Bank area and examine the cumulative impacts on productivity, habitat, biodiversity, and endangered or threatened species. From the data available, we can examine trawling and dredging disturbances, exploitation of marine resources by fisheries, fishing-gear entanglement threats to marine mammals and sea turtles, and vessel collision threats due to marine traffic, and vessel-noise disturbances. Each threat can be normalised on a zero-one scale to compare the intensity of threats across the region and then weighted and combined to examine cumulative anthropogenic threats as in Coll et al. (2012).

RESULTS

Most analyses have not been completed. The effort so far has been to assimilate and develop the scaffolding to support the analyses and future monitoring and assessment. These headings are here mostly as place holders. However, some preliminary results can be reported upon to show direction. We highlight a few of these results but emphasize their very preliminary nature.

BIODIVERSITY

No analytical results are available for presentation at this time.

PRODUCTIVITY

At present, only the models for Snow Crab have been completed using this method (Figure 34; see Choi et al. 2012 for more details).

HABITAT

Functional Habitat

At present, only the models for Snow Crab have been completed using this method (Figure 35 and 36; see Choi et al. 2012 for more details).

Integral Habitat

An example of **Integral habitat** (H_i) as expressed through an ordination of taxa found together in various bottom trawls (Figure 37).

CONNECTIVITY

Spatial Scale

This is a first attempt at describing the spatial scale of SAB and outlying areas. Essentially, S_s represents the distance one must walk before one loses memory of where one started (arbitrarily defined at the 5% level of autocorrelation). Using this level of similarity as the standard, depth variations are demonstrably patchy/clustered (Figure 38). In the SAB area, there is a mixture of large autocorrelation scales (exp(6)=400 km) in the north-east areas, while the south-west areas have spatial scales of approximately 20 km or less.

Recall that if S_s is small, then short-range processes dominate (e.g., less mobile species, weakly dispersing, low currents, habitat heterogeneity at small scales). If S_s is large, then broader/larger processes were influencing the productivity of the species (e.g., higher mobility or dispersal processes/current, and stronger spatial connectivity, habitat heterogeneity at larger scales).

As an another example, Snow Crab densities suggest different spatial autocorrelation patterns (Figure 39), with the majority of core fishing grounds being in the range of 60-90 km in length scale. In the vicinity of SAB, these spatial scales decline to about 10-60 km.

Temporal Scale

Similar to spatial scale, we have defined temporal scale (S_t) as the time required to reach a state where autocorrelation drops to an insignificant level (5%). Recall that if S_t is small, short-range variations dominate (higher sampling effort to resolve/describe). If S_t is large, long-range variations dominate (lower sampling effort required to resolve/describe). No analytical results are available for presentation at this time.

Tagging

No analytical results are available for presentation at this time beyond the overviews.

DISCUSSION

No discussions are forthcoming until more analysis can be completed.

CONCLUSIONS AND RECOMMENDATIONS

This report was an exercise in demonstrating what is available and possible. All methods discussed are viable and informative and so should serve as a strong basis for any future monitoring framework in SAB and MPAs in general.

ACKNOWLEDGEMENTS

We highlight the invaluable assistance of a great number of scientists that have been part of the various surveys that inform this document. This report could not have been completed without their guidance and assistance: Shelley Bond (DataShop), Carla Caverhill, George White (Remote Sensing Group), Catherine Johnson, Benoit Casault (Atlantic Zone Monitoring Progarm), Ben Zisserson, Brent Cameron, Snow Crab industry (Snow Crab survey), Scott Wilson, Bill MacEachern, Don Clark (groundfish survey), Dale Roddick (clam survey), Vladimir Kostelev, Charles Hannah (substrate grain size), Canadian Hydrographic Service (bathymetry data), Roger Pettipas (Ocean Sciences, ocean temperature data), Robert Grandy, Greg Croft and Krista Wry (Commercial Data Division), and Tanya Koropatnick and Norman Cochrane (vessel data).

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FIGURES

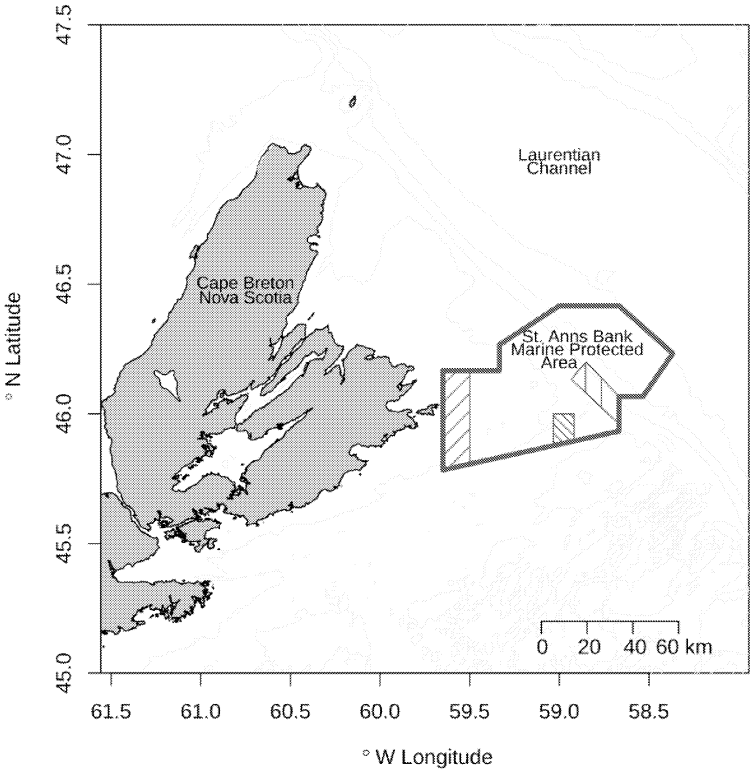

Figure 1. Bathymetric chart of the St. Anns Bank (SAB) area with the proposed Marine Protected Area (MPA, thick line) and limited fishing zones (hatched areas). See Figure 2 for geographic location in a larger map.

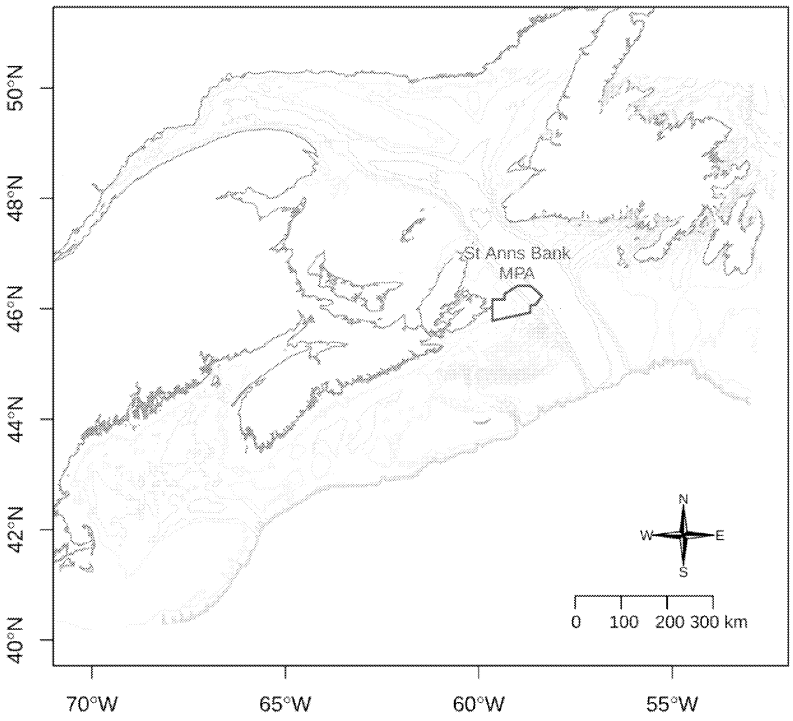

Figure 2. Map of the data extraction area 37°N to 48°N and from 48°W to 71°W and the relative location of the St. Anns Bank MPA.

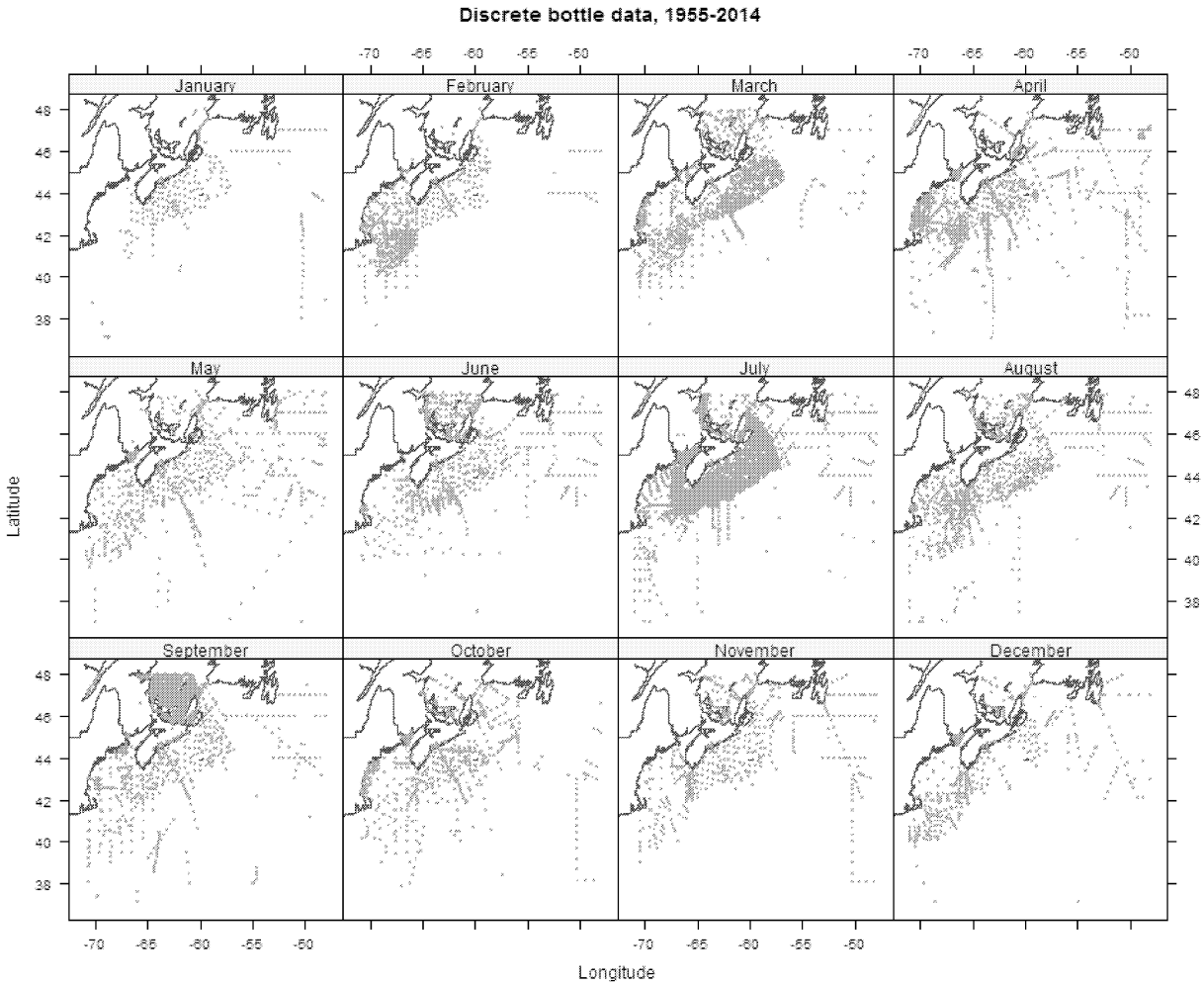

Figure 3. Monthly spatial distribution of discrete bottle data for the time period 1955-2014.

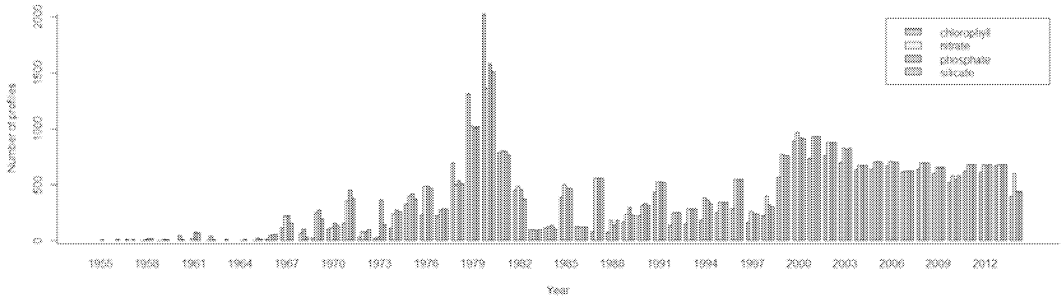

Figure 4. Number of chlorophyll and nutrient profiles extracted from the BioChem database for each year since 1955.

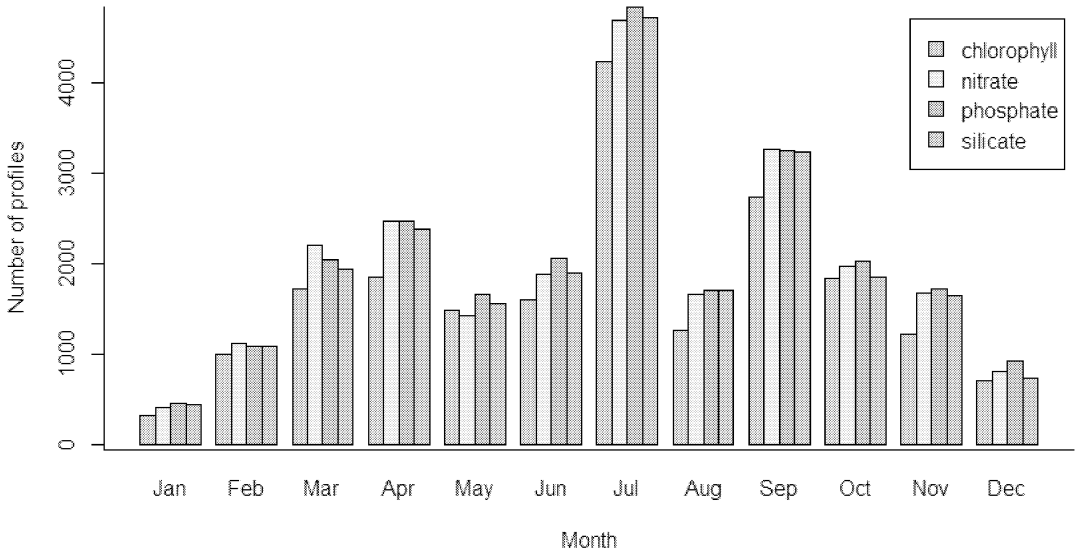

Figure 5. Number of chlorophyll and nutrient profiles extracted from the BioChem database for the time period 1955-2014, grouped monthly.

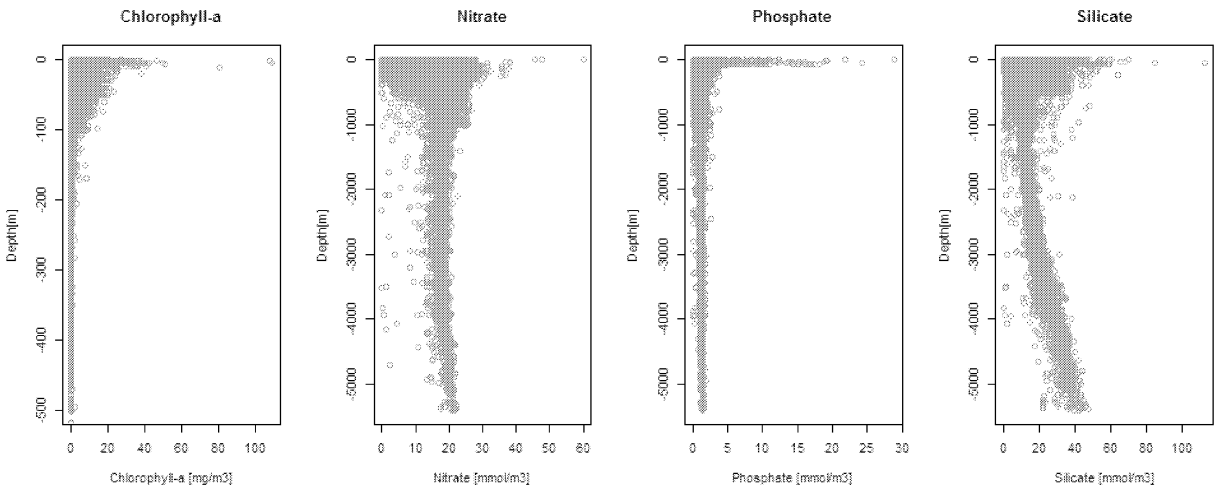

Figure 6. Depth profiles of chlorophyll-a and nutrients; all data for the time period 1955-2014.

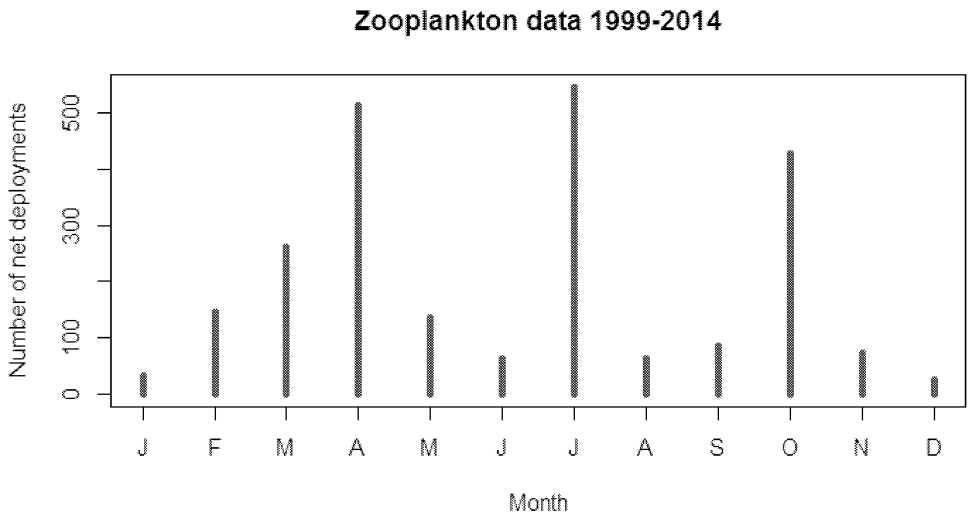

Figure 7. Total number of net deployments for each month during the time period 1999-2014.

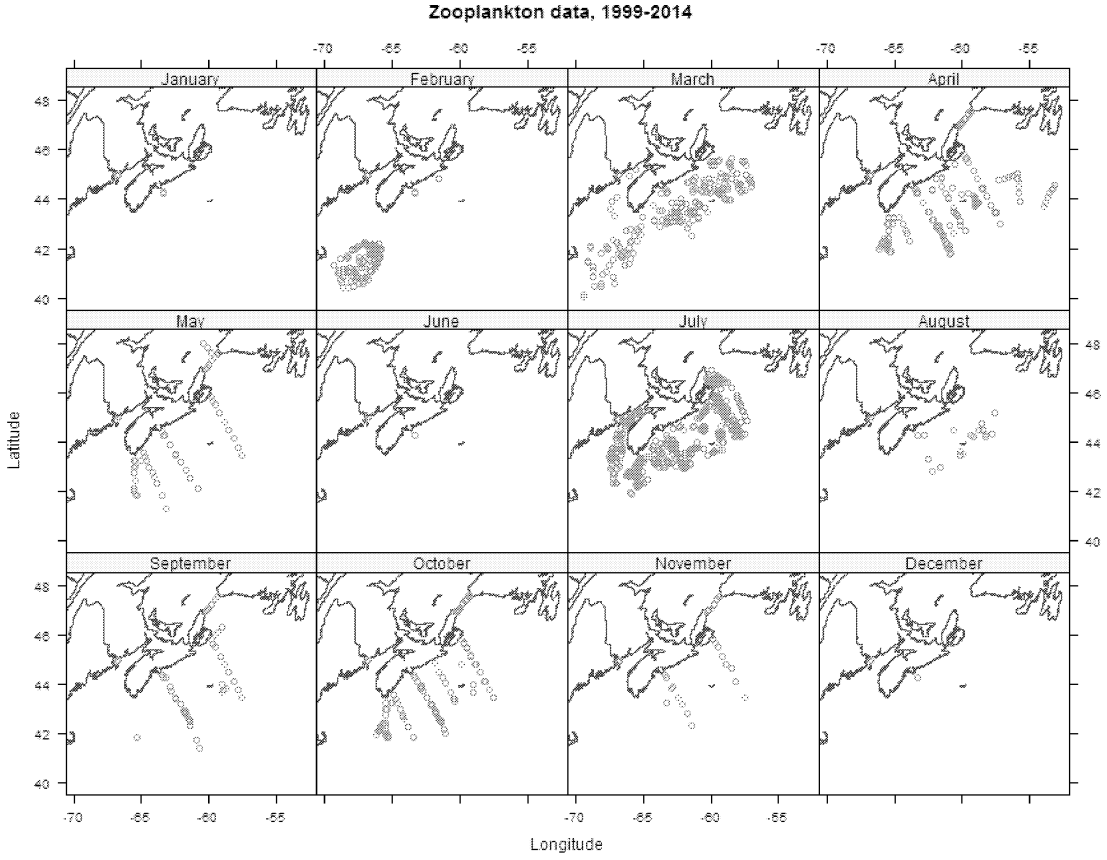

Figure 8. Total number of net deployments for each month during the time period 1999-2014.

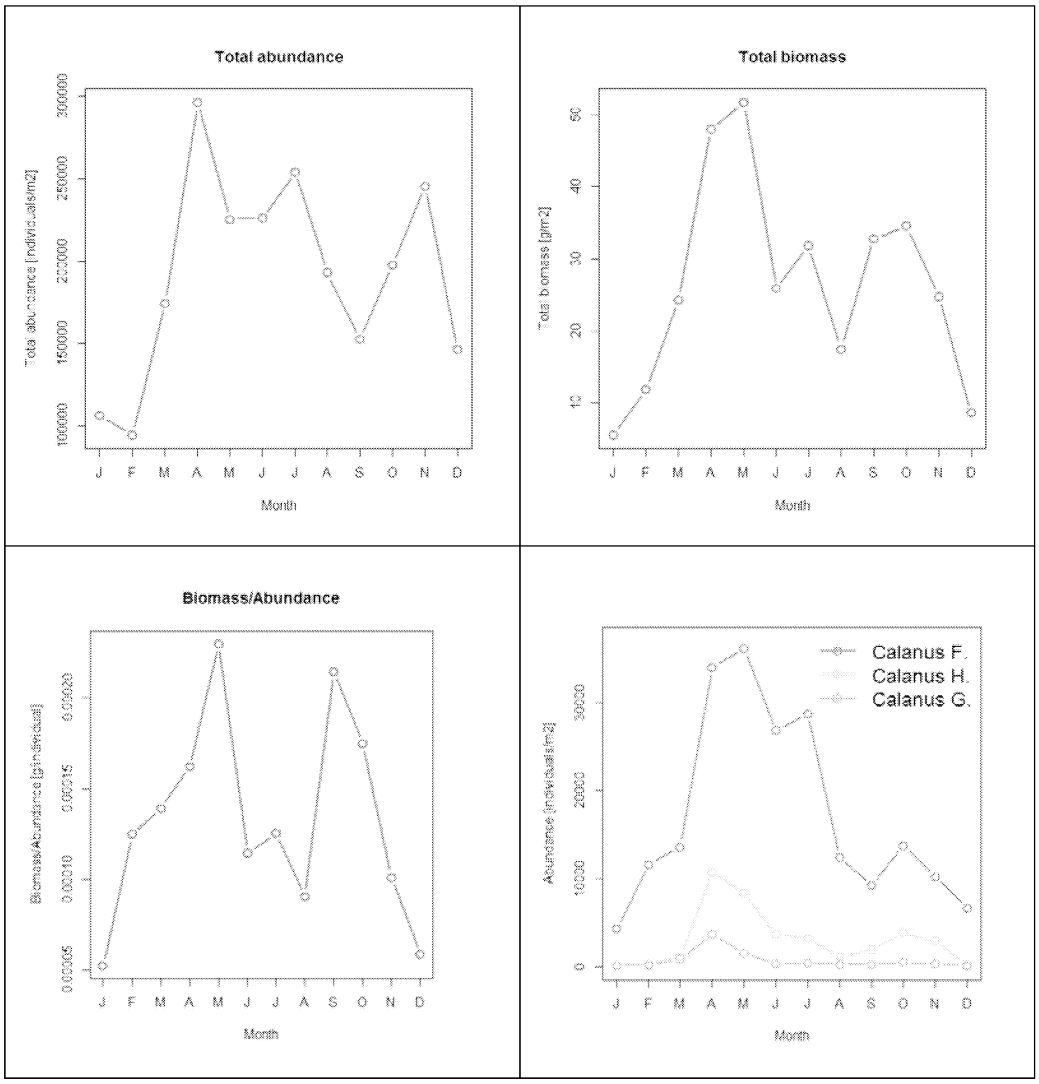

Figure 9. Monthly averages of all data from 1999 to 2014: total abundance (top left), total biomass computed from wet weight (top right), ratio of total biomass computed from wet weight to total abundance (bottom left) as a potential measure of the average weight of the individual organism, and abundance of Calanus finmarchicus, C. hyperboreus, and C. glacialis (botton right).

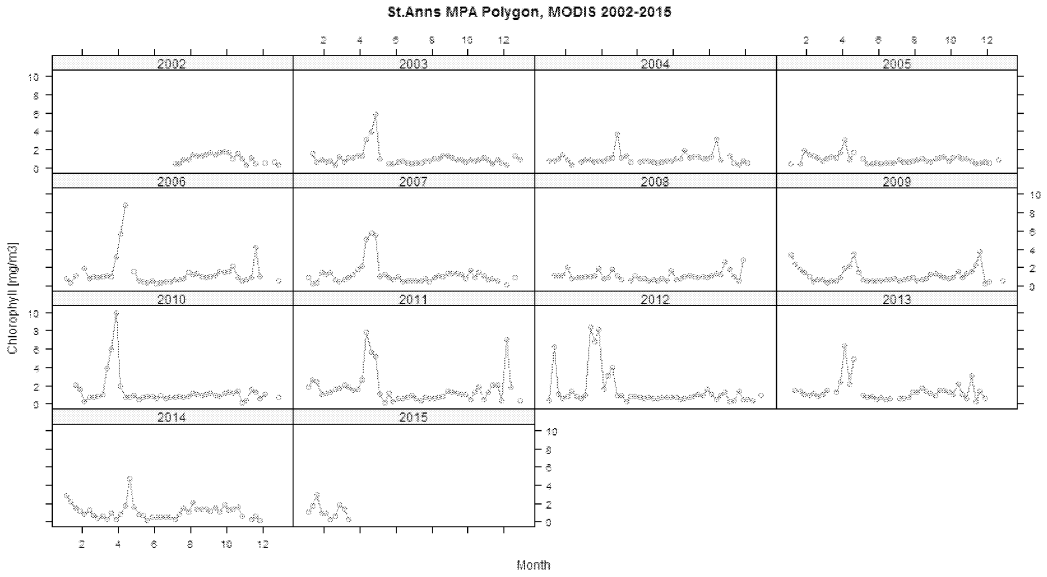

Figure 10. Chlorophyll-a concentration extracted from MODIS 8-day composite images for St. Anns Bank polygon for the time period 2002-2015.

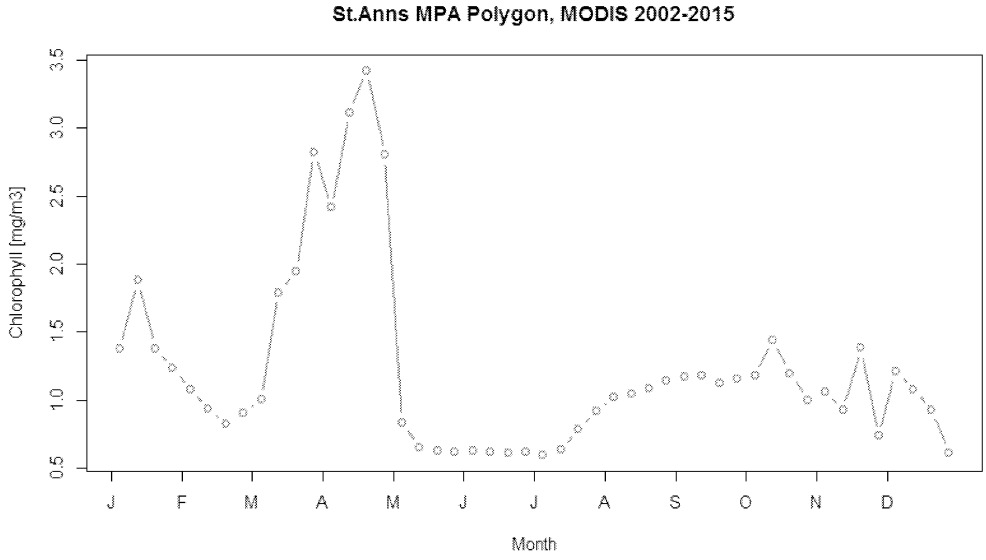

Figure 11. Average Chorophyll-a concentration computed from 8-day composite images for St. Anns Bank polygon for the time period 2002-2015.

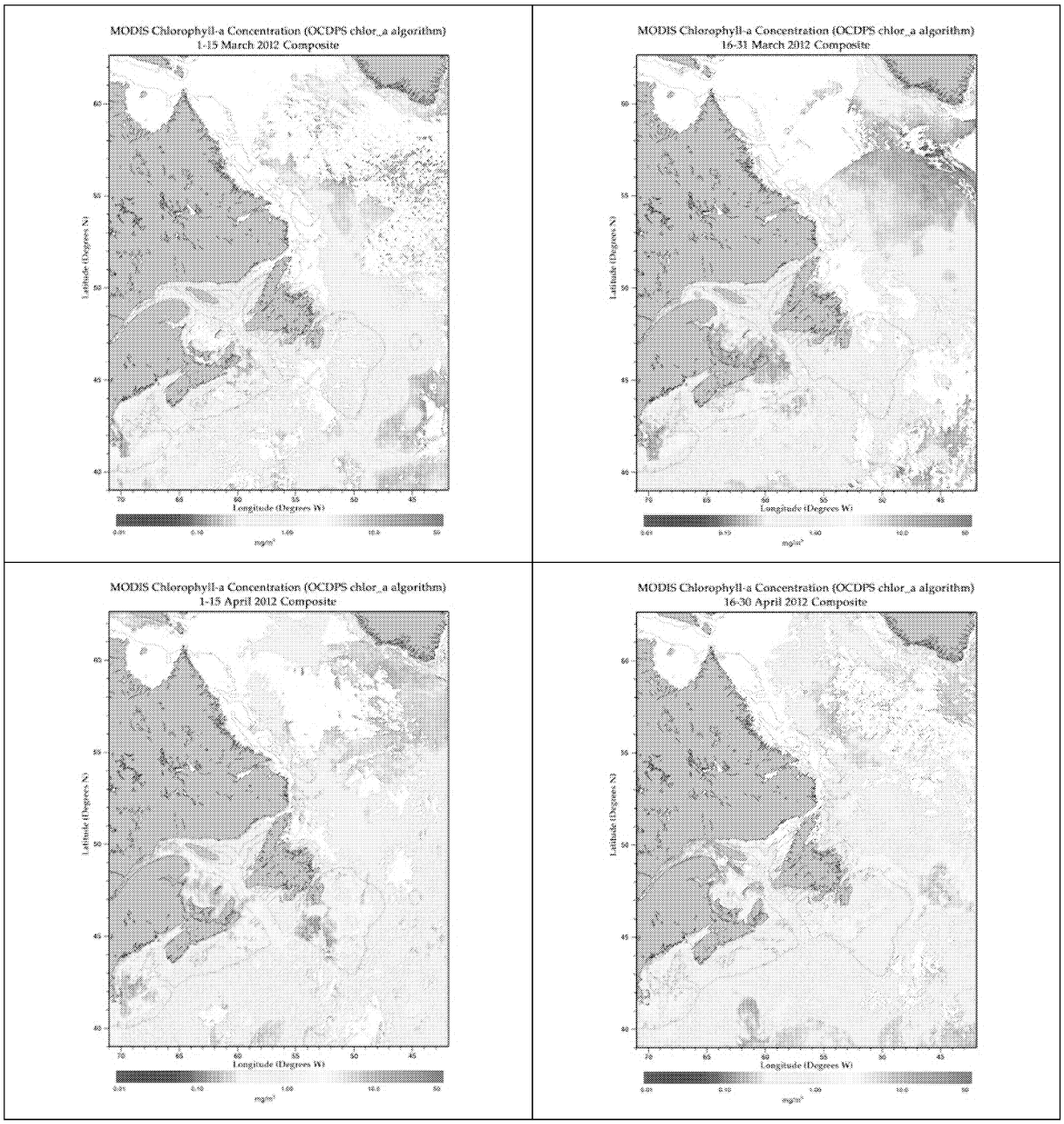

Figure 12. MODIS semi-monthly chlorophyll-a concentration showing spring bloom progression in the Northwest Atlantic in 2012. Note the intense bloom at St. Anns Bank during the last two weeks in March.

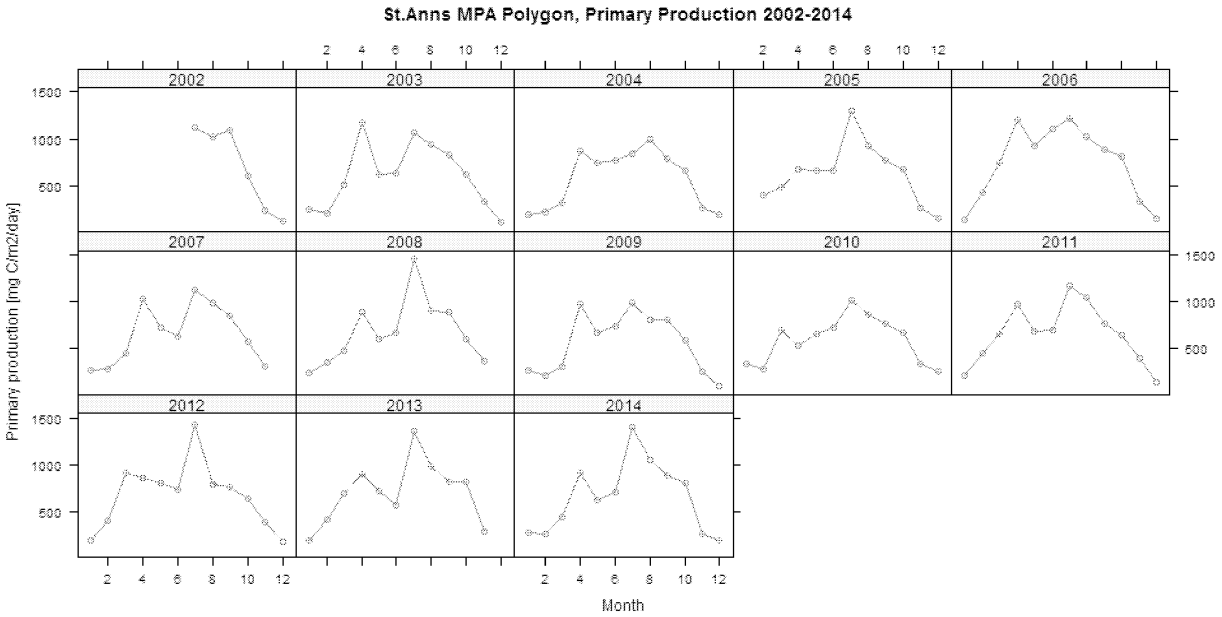

Figure 13. Annual monthly Primary Production (PP) computed from PP composite images for St. Anns Bank polygon for the time period 2002-2014.

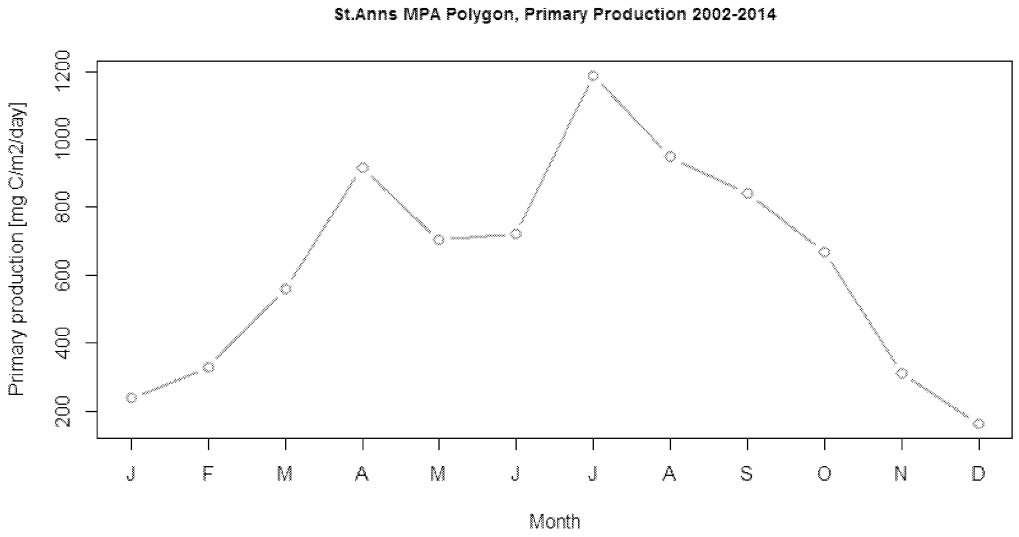

Figure 14. Average Primary Production (PP) computed from monthly composite images for St. Anns Bank polygon for the time period 2002-2014.

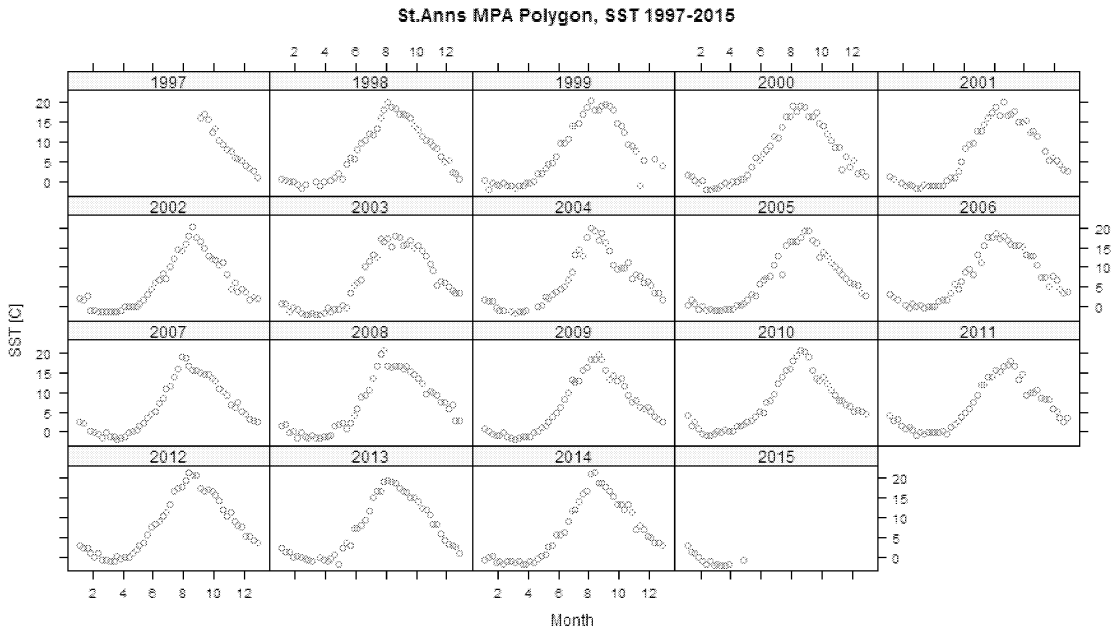

Figure 15. Sea Surface Temperature (SST) extracted from 8-day AVHRR composite images for St. Anns Bank polygon for the time period 1997-2015.

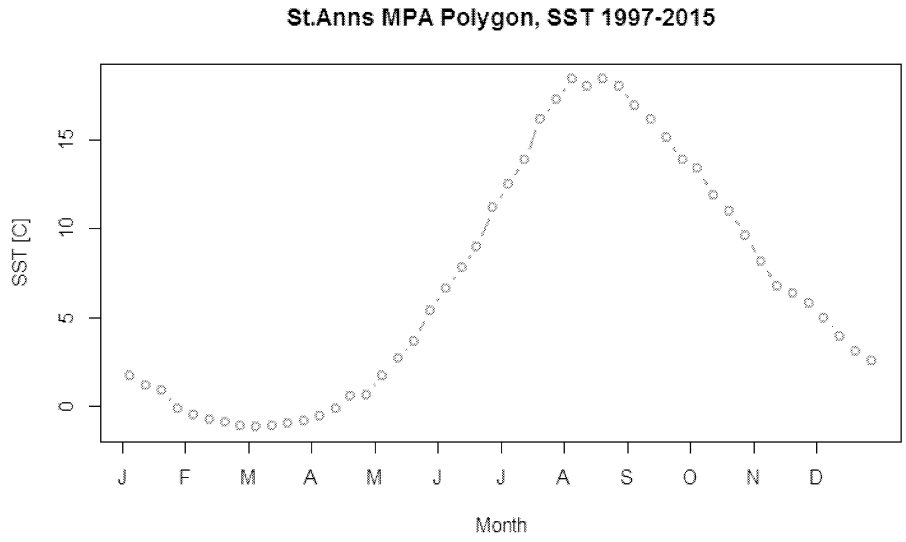

Figure 16. Average Sea Surface Temperature (SST) computed from 8-day AVHRR composite images for St. Anns Bank polygon for the time period 1997-2015.

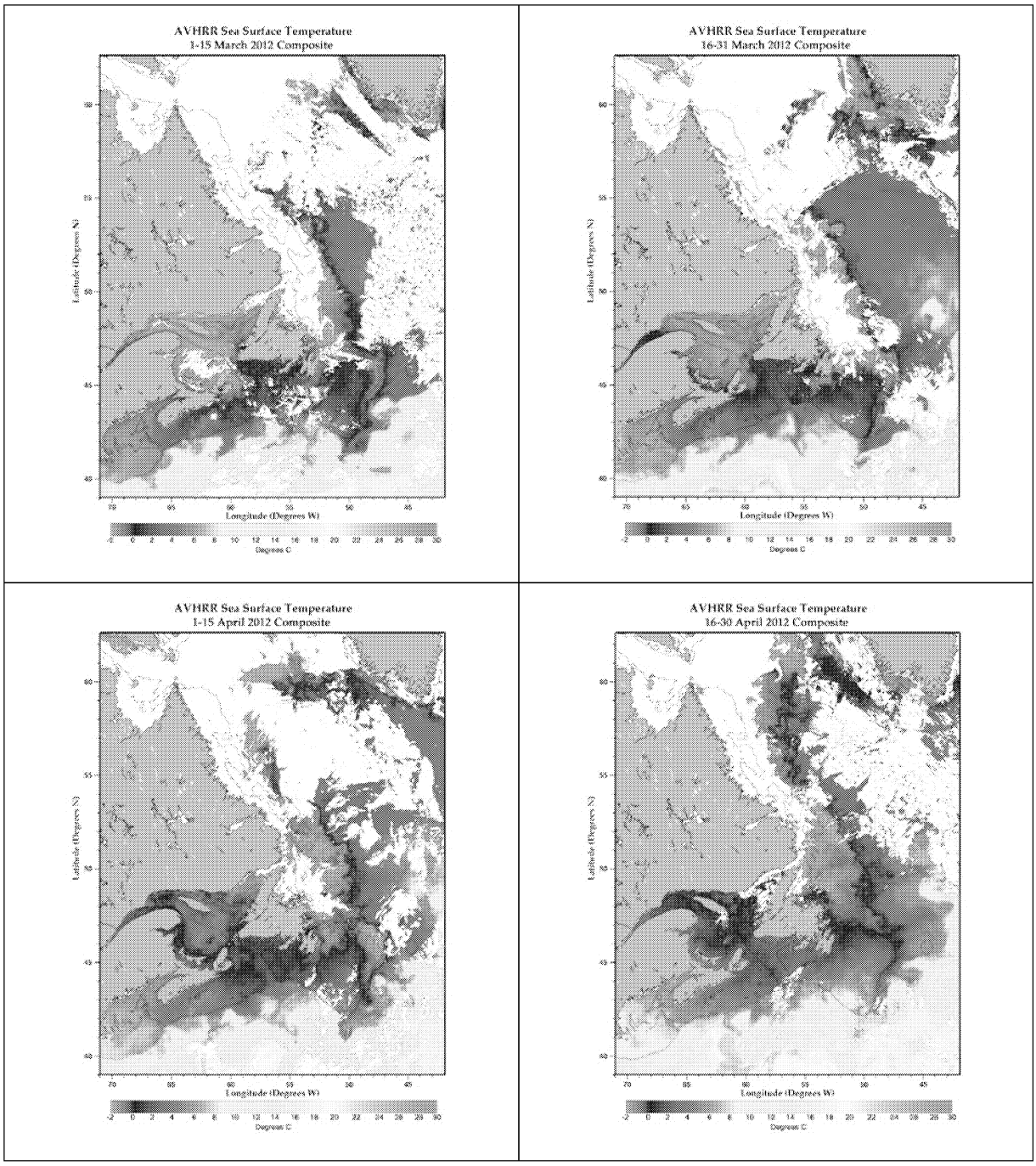

Figure 17. Bi-weekly composites from AVHRR showing SST in the Northwest Atlantic in the spring of 2012, corresponding to the intense spring bloom at St. Anns bank shown in Figure 2.

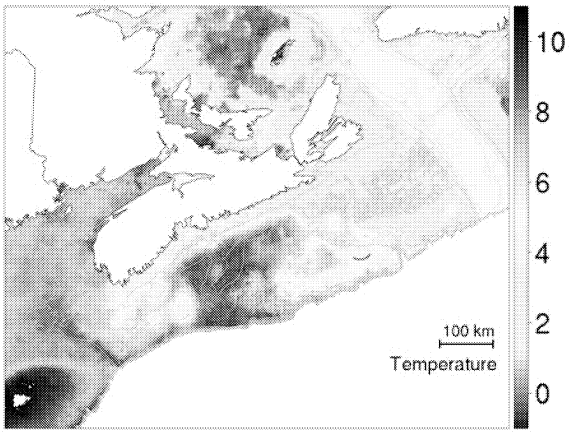

Figure 18. Average bottom temperatures computed from all available data 1950-2016.

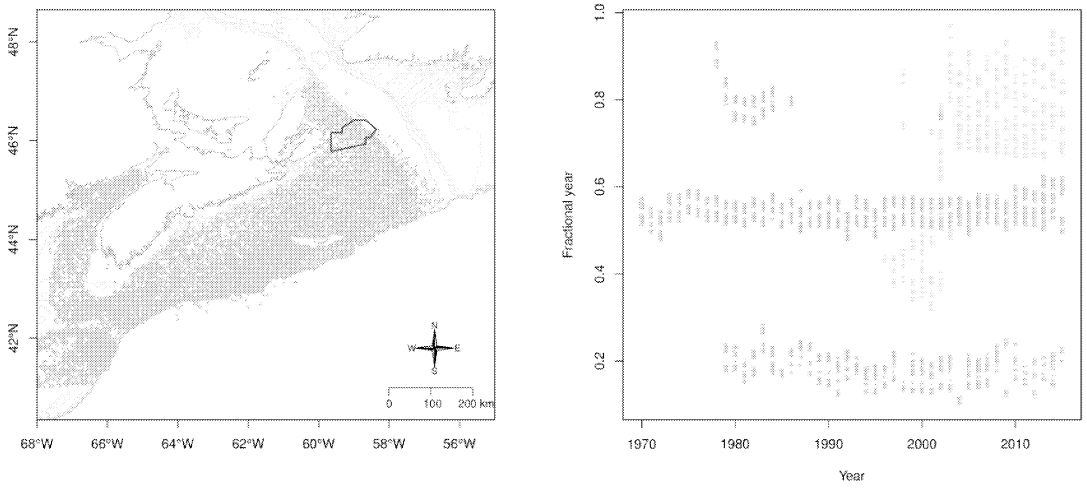

Figure 19. Left: Survey locations in the Groundfish survey (orange) and Snow Crab survey (green). Right: Timing of surveys in the Groundfish survey (orange) and Snow Crab survey (green).

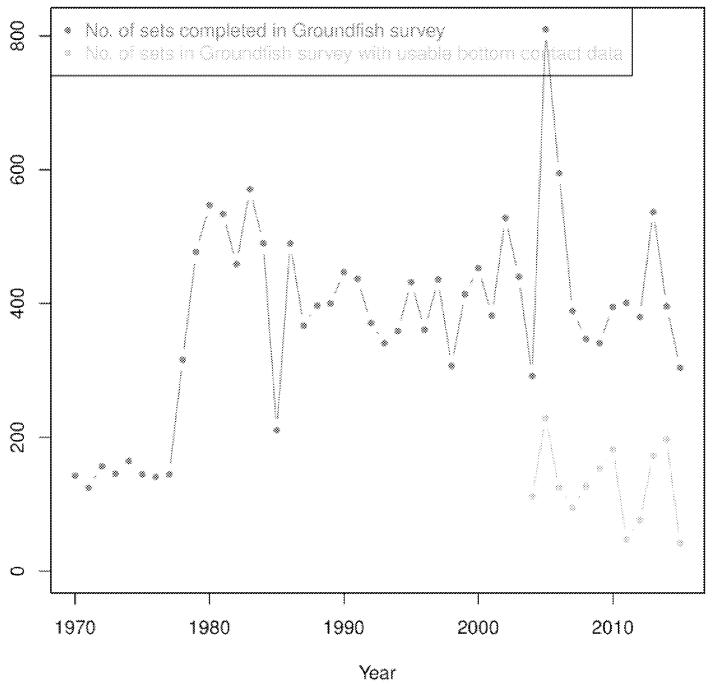

Figure 20. Number of sets in the groundfish surveys (blue) and the number of sets with usable net configuration data (orange).

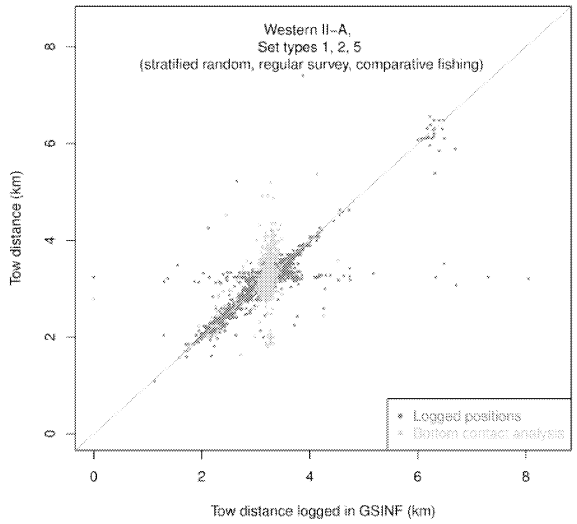

Figure 21. Towed distance comparisons in the groundfish survey.

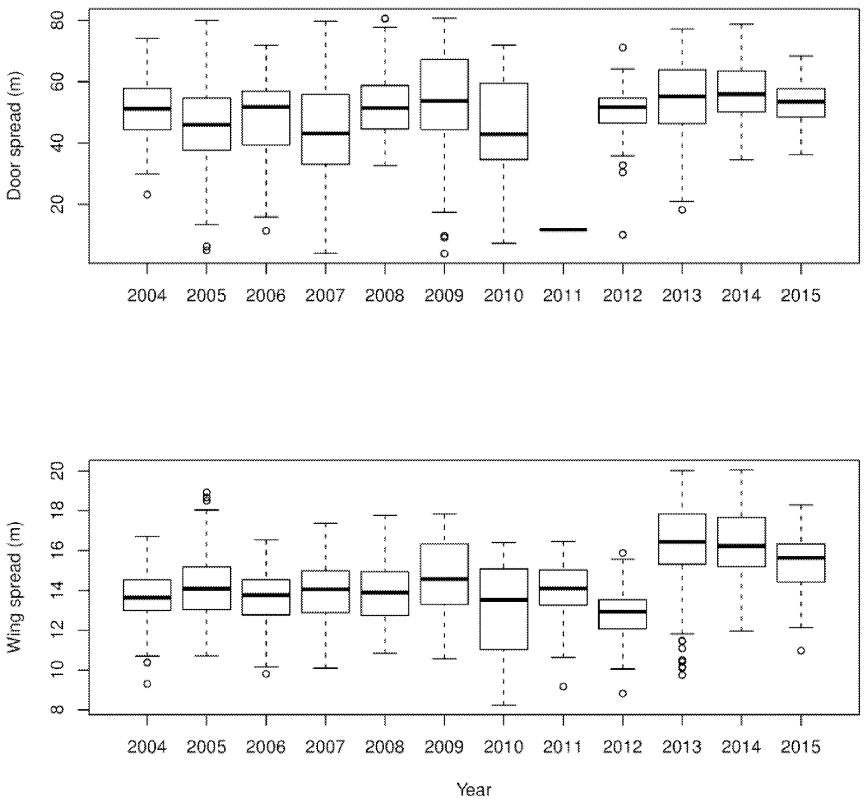

Figure 22. Net spread variations by year. Note in 2011, the doorspread sensors seem to have failed completely. Note also that wingspread has been significantly larger from 2013 to 2015.

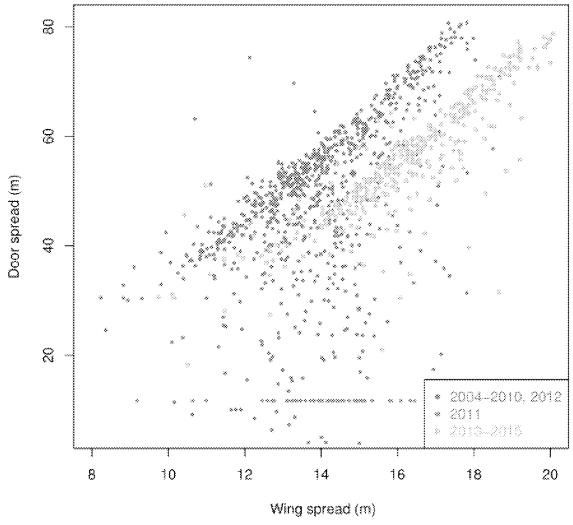

Figure 23. Net spread variations: doorspread vs wingspread. Note also that wingspread has been significantly larger from 2013 to 2015 but not doorspread. The cause of this divergence is not known.

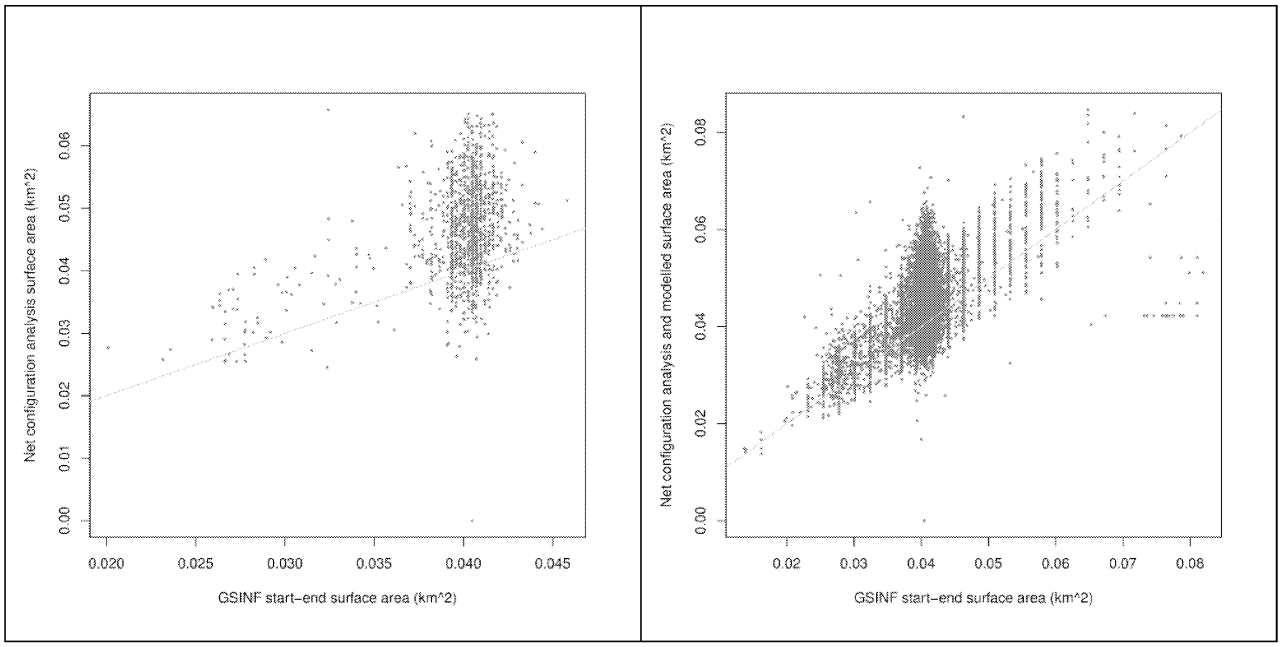

Figure 24. Left: Surface area estimates based on GSINF logged start-end positions vs computed surface area estimated from tow track and net configuration. Right: Surface area estimates based on GSINF logged start-end positions vs computed surface area estimated from tow track and net configuration, ***as well as, modeled solutions****.*

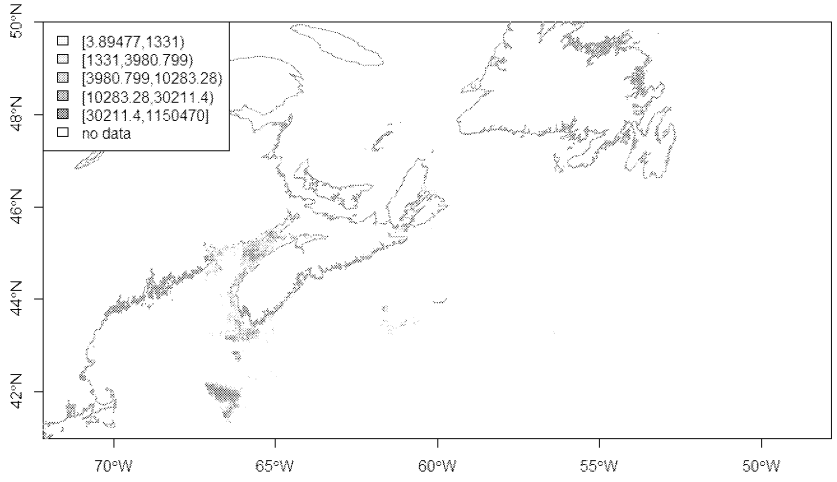

Figure 25. Commercial catch weights of Sea Scallops (Placopecten magellanicus) on Georges Bank, the Scotian Shelf, and in the Bay of Fundy.

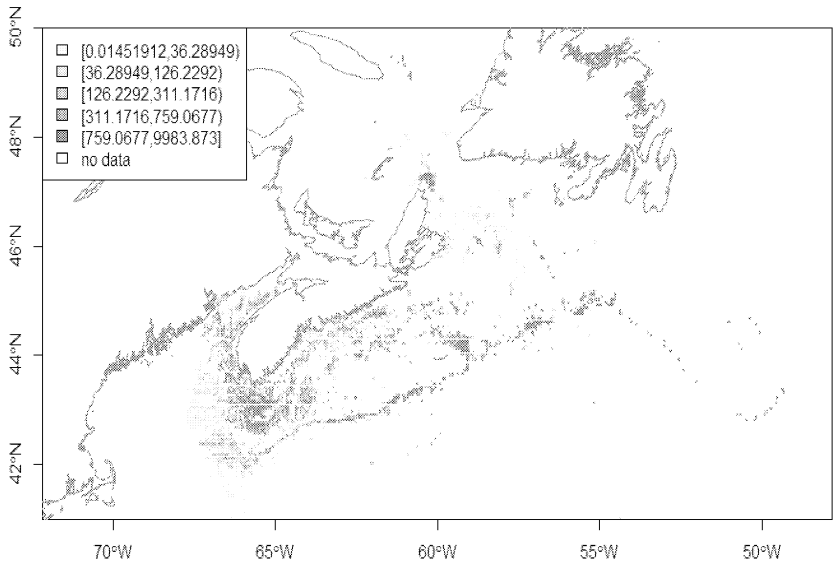

Figure 26. Commercial catch weights of Atlantic Halibut (Hippoglossus hippoglossus) on Georges Bank, the Scotian Shelf, and in the Bay of Fundy.

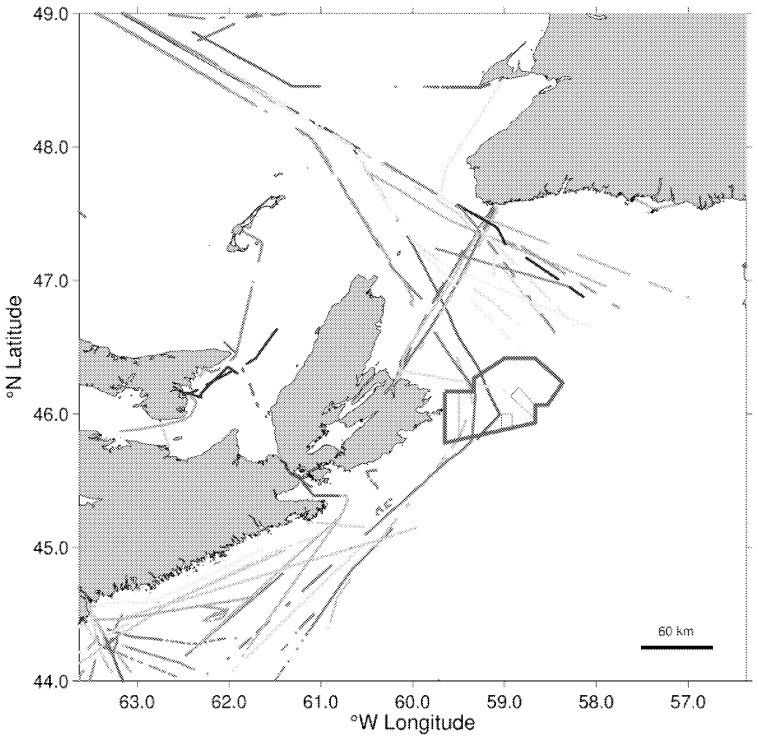

Figure 27. Automatic Identification System (AIS) data collected from the Canadian Coast Guard terrestrial network of AIS receiving stations on December 8, 2015. A total of 127 vessels were detected in the area with each colour representing a unique vessel.

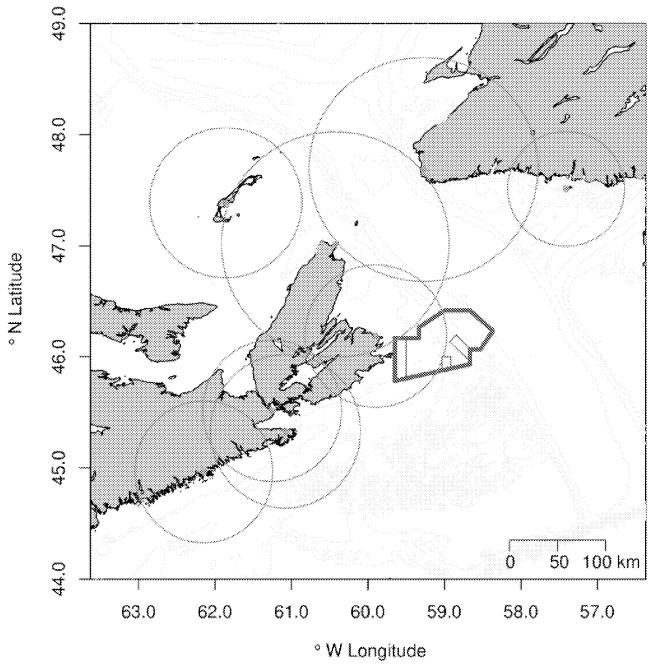

Figure 28. Bathymetic (100 m resolution) chart of the St. Anns Bank area with line of sight detection (red circles) for the terrestrial AIS receiving stations (red dots) around St. Anns Bank Area of Interest.

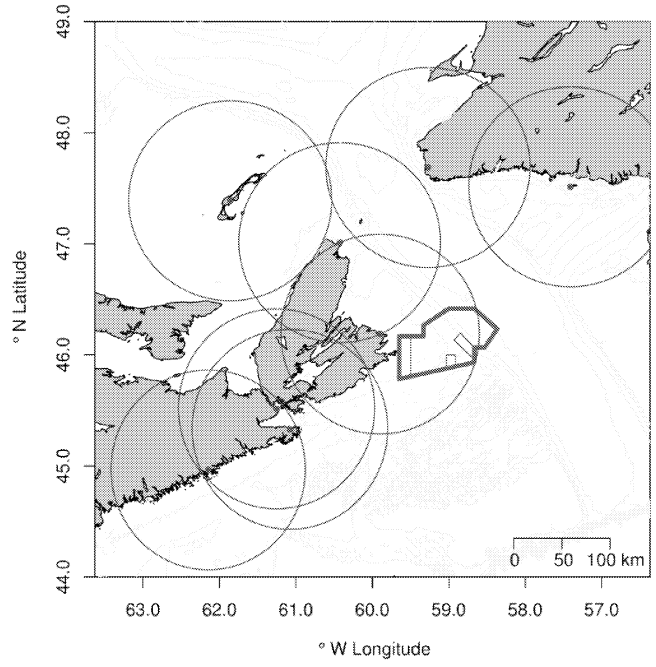

Figure 29. Bathymetic (100 m resolution) chart of the St. Anns Bank area with Simard et al. (2014) estimated vessel detection distances (blue circles) for the terrestrial AIS receiving stations (blue dots) around St. Anns Bank Area of Interest.

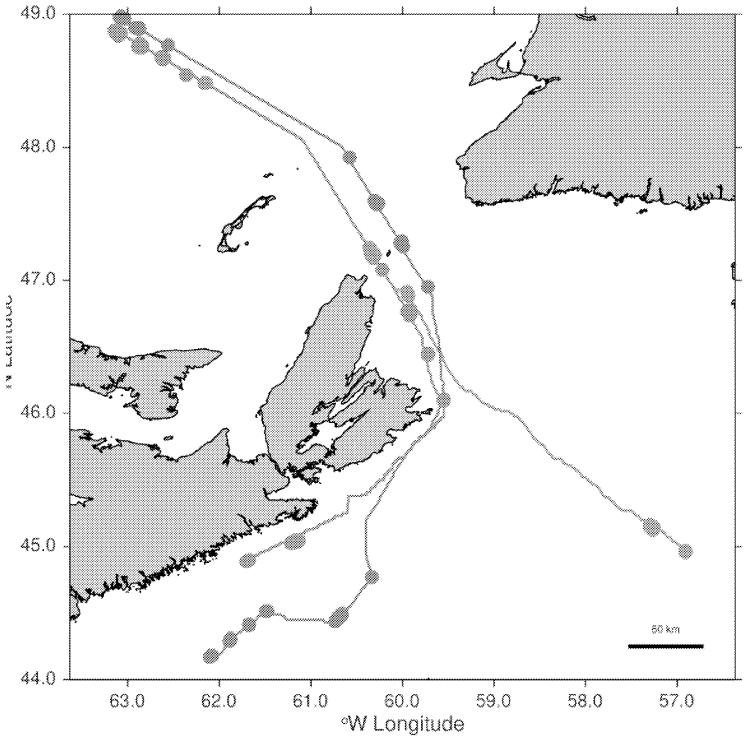

Figure 30. Hypothetical vessel positions (large filled circles) and interpolated vessel positions (lines) based on the A algorithm for three vessels transiting through the St. Anns Bank area. Each colour represents a unique vessel.*

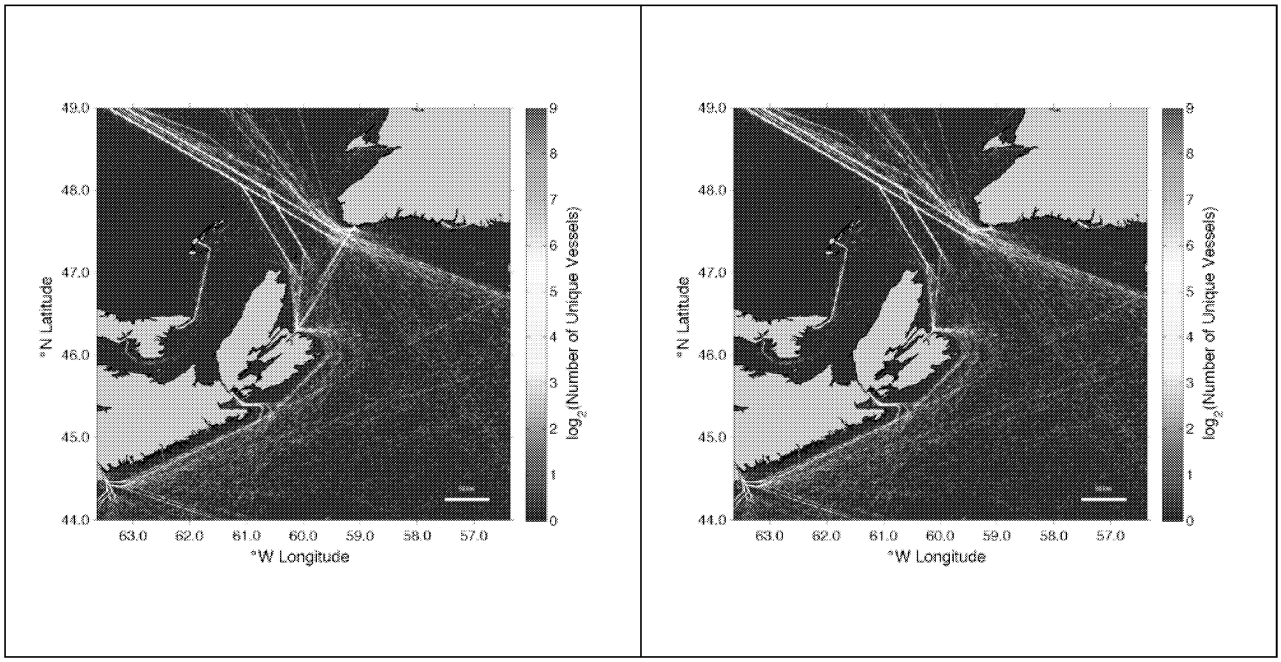

Figure 31. Vessel density maps for the first quarter of a year based on satellite AIS data from 2013-2015 for all vessels (left panel) and all vessels except of the Newfoundland ferries (right panel).

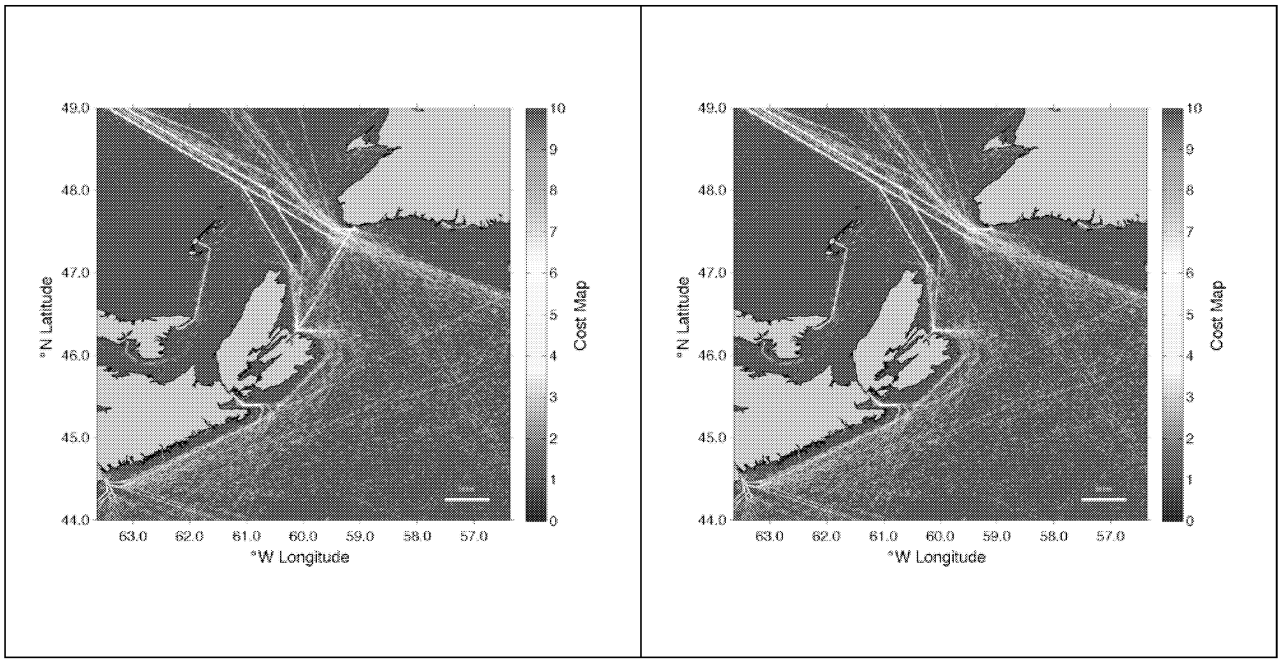

Figure 32. Cost maps developed for the A function to interpolate undetected vessel positions as vessels transit in and out of the Gulf of St. Lawrence.*

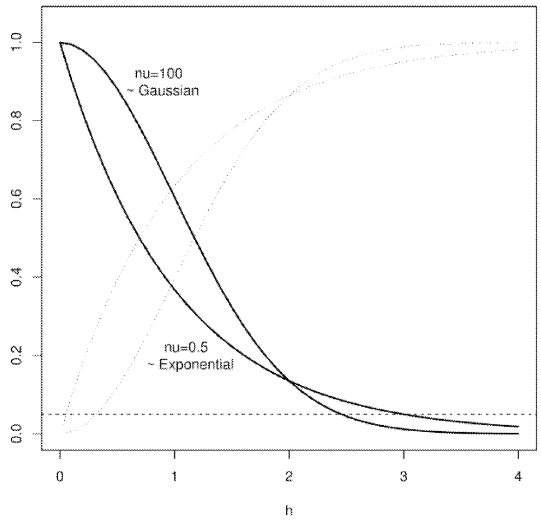

Figure 33. Matérn autocorrelation function, $\rho(h) = C(h)/C(0)$, the covariance function $C(h)$ scaled by the total variance $C(0)$, for two values of ν (dark lines). At $nu = 100$, it approaches the Gaussian curve (upper dark curve on the left side) while at $\nu = 0.5$ the curve is exponential (lower dark curve on the left side). The associated semi-variograms (scaled to unit variance) $\gamma(h)$ are shown in light stippled lines. Spatial scale is defined, in this framework, as the distance h at which the autocorrelation falls to 0.05% (dashed horizontal line) – in this example between 2.5 and 3 units, depending upon value of ν.

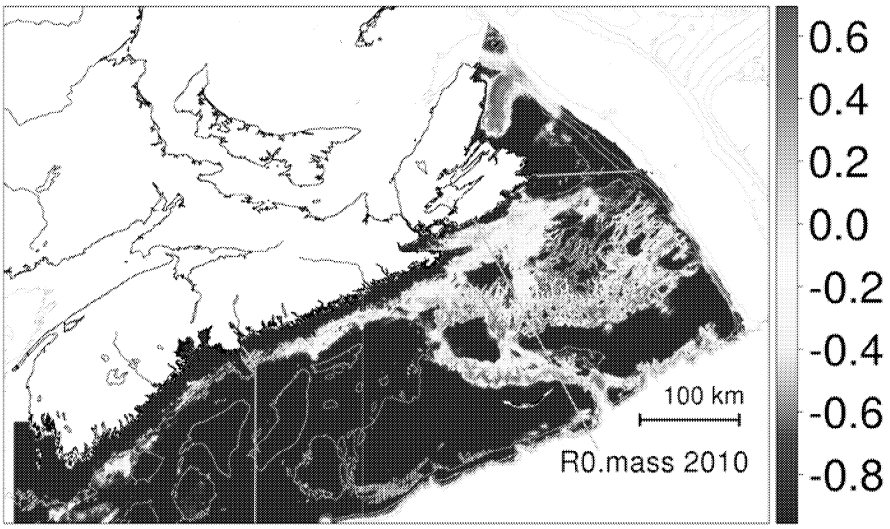

Figure 34. Predicted biomass density of Snow Crab in Maritimes Region based upon a combination of a Functional-habitat method and simple spatial interpolation.

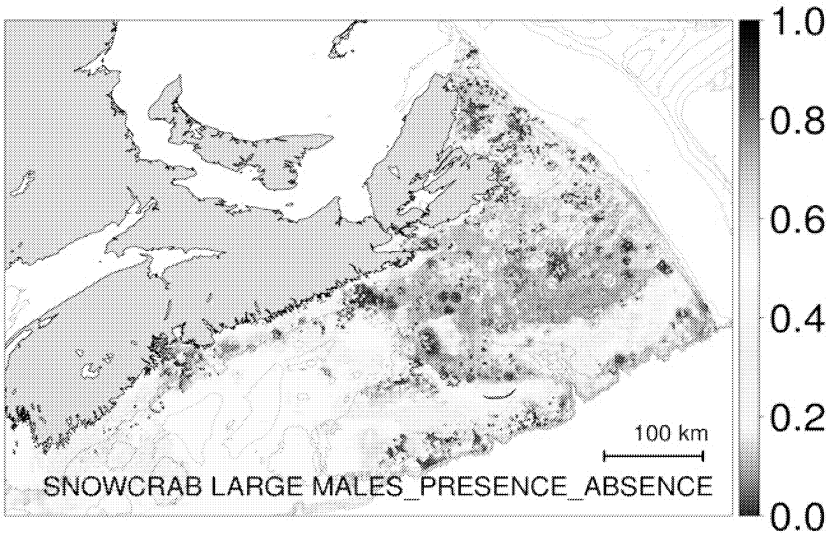

Figure 35. Functional habitat, (H_f), the predicted probability of observing Snow Crab.

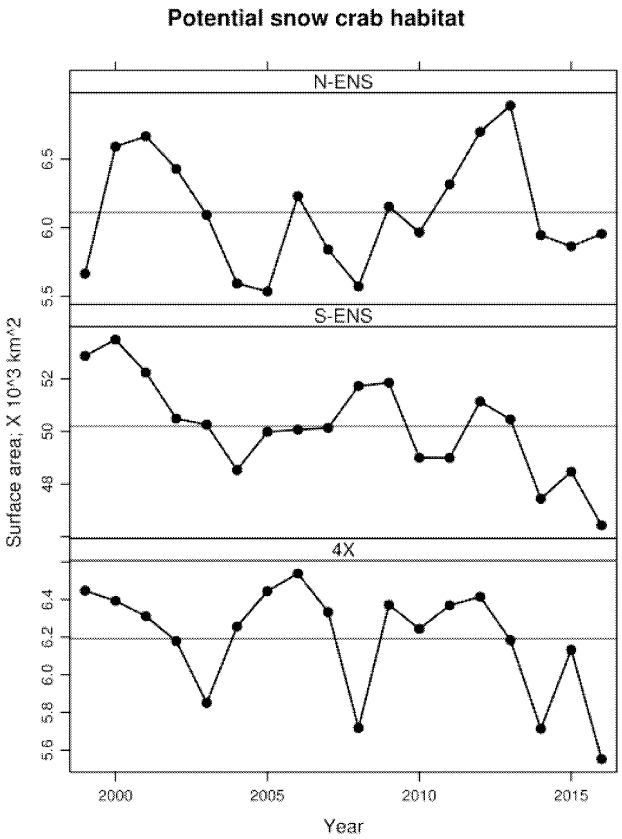

Figure 36. Surface area of potential Functional habitat (H_f) of Snow Crab in Maritimes Region. Note the large interannual variability and a decadal scale decline in the southern areas (lower two panels).

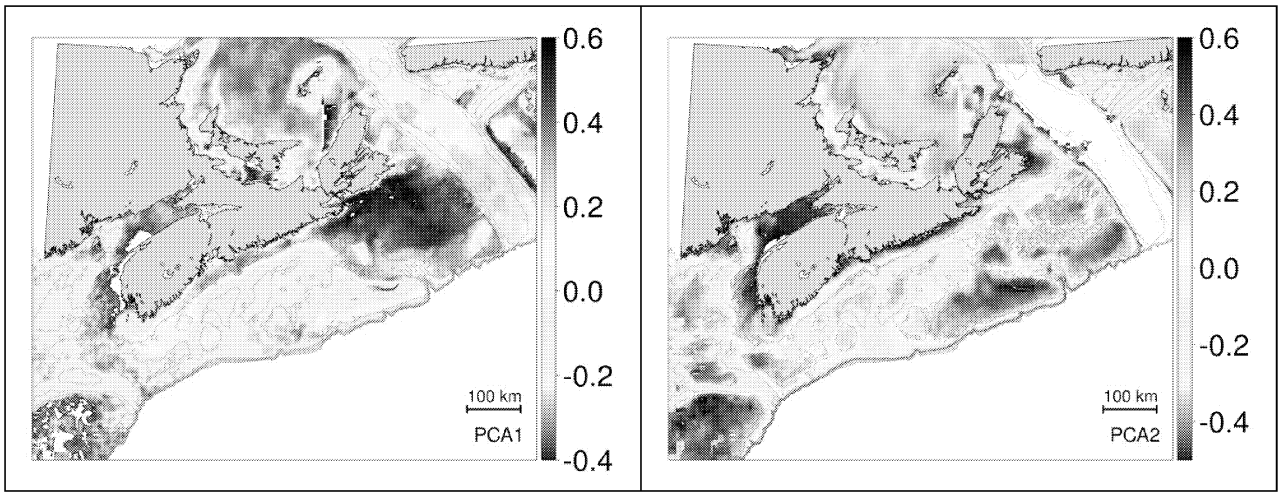

Figure 37. Integral habitat (H_i) based upon species associations in Maritimes Region. Note the first axis is primarily a temperature gradient and the second associated with depth.

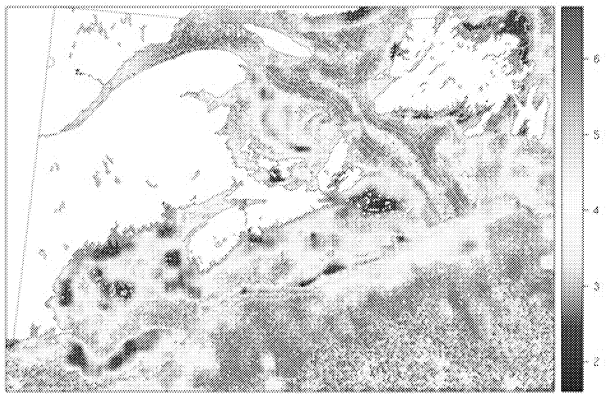

Figure 38. First estimate of log(spatial range; km) based upon depth variations.

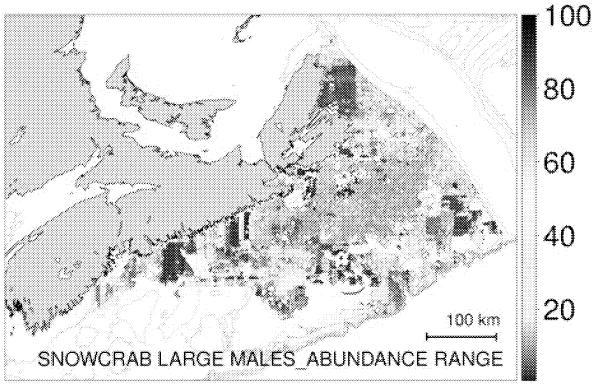

Figure 39. A first estimate of log_e(spatial range; km) of Snow Crab abundance variations.

APPENDICES

APPENDIX 1. DATA QUALITY CONTROL OF AZMP DATA

All data extraction, quality control and processing methods are documented in R scripts found in https://github.com/jae0/aegis/.

DISCRETE BOTTLE DATA

BioChem data are generally not subject to any quality control (QC). As such, substantial QC was required. The QC protocol used was based on procedures designed at DFO's Institut Maurice-Lamontagne (IML). These were in turn based on procedures developed by NOAA's National Oceanographic Data Center/World Ocean Database, as well as many of the tests proposed in the GTSPP Real-Time Quality Control Manual. The quality control procedure was as follows:

Step 1: Impossible Dates

Due to known issues with dates, database query for nutrients and chlorophyll were designed to extract records for which the sampling date is within start and end dates of the mission. Another check includes comparing HEADER_START and EVENT_START dates that should be the same. It is often found that month and day were reversed in EVENT_START field. Those records were retained and HEADER_START was used as a more reliable date.

Step 2: Quality Control Flags

A small number of records in BioChem was subject to quality control and include flags for position (POSITION_QC_CODE) and data (DATA_QC_CODE). The meaning of the codes are as follows:

- 0 = No quality control performed
- 1 = Value appears correct
- 2 = Value appears inconsistent
- 3 = Value appears doubtful
- 4 = Value appears erroneous
- 5 = Value changed as result of quality control

The QC flags were checked for parameter and inconsistent (2), doubtful (3) and erroneous (4) values were removed from the dataset.

Step 3: Depth Check

For bottle data, start and end depth at which the water samples were collected are verified to be the same. Records with different start and end depths were removed from the dataset.

Step 4: Duplicated Records

BioChem often contains duplicated records as the same data was sometimes loaded into a database twice and treated as different records. Duplicated records were removed, and the first record of each duplicate is kept in the dataset.

Step 5: Suspect Missions

Missions with suspect data were identified and removed. Those missions often show unusual data values (for example, integer numbers without decimal places with only some values out of

range), suggesting that the data for the whole mission might be compromised. The suspect mission for each parameter are following:

- Chlorophyll-a OC7908, 32G879008
- Phosphate 18HU88026
- Silicate 180167005, 31TR26870

Chlorophyll and all nutrients values were examined if they fell within expected limits for the Northwest Atlantic, which are adopted from IML quality control procedure (IML Test 2.1). The expected range of values are:

- Chlorophyll-a: 0-50 mg/m^3
- Nitrate: 0-515 mmol/m^3
- Phosphate: 0-4.5 mmol/m^3
- Silicate: 0-250 mmol/m^3

Any values outside of expected range were removed for open ocean data only. Coastal data (up to 5 km from the coast) were not filtered using expected ranges as in coastal water chlorophyll-a and nutrients concentrations can be higher.

Step 6: Profile Envelope

Data for each parameter are checked if they fall within the expected limits by depth interval, as shown in Table A1.1 (IML Test 2.4). This test does not allow zero values for silicate and phosphate in the deep water. Again, only open ocean data were subject to the profile envelope test.

Table A1.1. Expected ranges of parameters for the profile envelope test (IML Test 2.4)

Parameter	Depth Interval	Expected Range
Chlorophyll-a	0-1500 m	0-50 mg/m^3
Silicate	0-150 m	0-250 mmol/m^3
Silicate	150-900 m	0.01-250 mmol/m^3
Phosphate	0-500 m	0-4.5 mmol/m^3
Phosphate	150-1500 m	0.01-4.5 mmol/m^3
Nitrate	0-1500 m	0-515 mmol/m^3

Step 7: Impossible Profiles

This check was not implemented in the code and impossible profiles were identified by investigating unusual outliers.

Additional steps from IML QC procedure, such as checks for constant profile, excessive gradient and inversions, were not implemented in this quality control procedure. However, due to eutrophication from terrestrial sources, phosphate levels in coastal regions often exceeded the upper limits for globally and locally possible values, with the phosphate concentrations sometimes six times higher than the upper limits for the Northwest Atlantic in offshore waters.

Therefore, coastal and open ocean data were examined separately; non-coastal data were filtered using the expected limits for the Northwest Atlantic. Coastal data were defined as the ones collected less than 5 km away from the coast, where a 5 km limit was chosen as an optimal distance at which all coastal inlets are included. Buffer polygons along the coastline were created (Figure A1.1) and used for flagging the data as open ocean records (Flag 1) and coastal records (Flag 2).

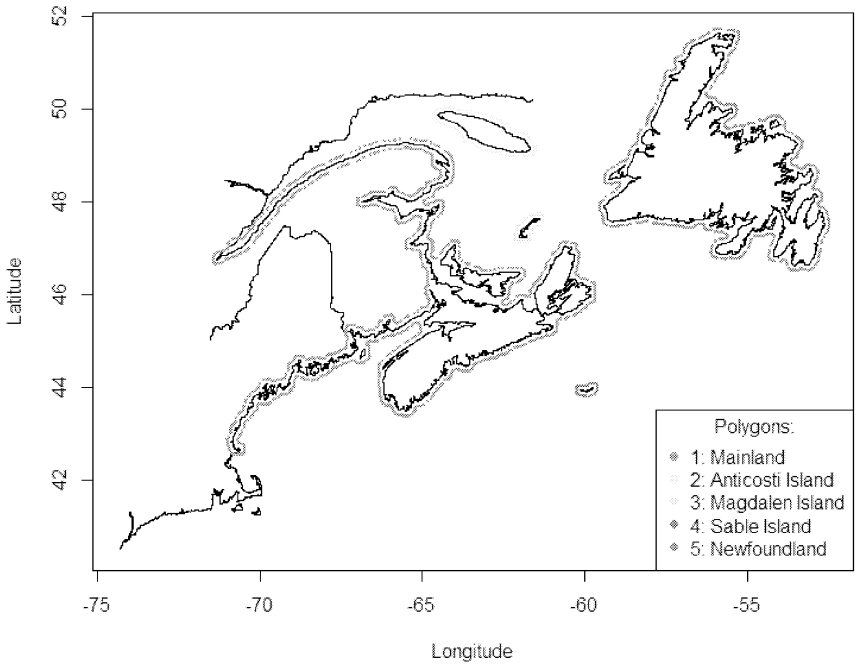

Figure A1.1. Polygons used for separation of coastal and ocean data, arbitrarily assumed to be a 5 km buffer from the coastline.

CHLOROPHYLL-A

Chlorophyll-a data are derived from four methods. The methods are listed and described in Table A1.2 and the aggregate time series associated with each method is shown in Figure A1.2. For most of the chlorophyll data, the method is not specified (unknown); Holm-Hansen fluorometric method is the standard AZMP method and is the second most frequent; Welschmeyer fluorometric method is used least frequently, often by the Quebec and Newfoundland regions.

In a number of cases, the same water sample was processed using two different methods, resulting in two sets of chlorophyll estimates for the same samples. Comparisons between these two sets of values are shown in Figure A1.3. In both cases, chlorophyll-a estimated by the Welschmeyer method are lower than the ones using the Holm-Hansen method or “unknown” method. Since there is more data mapped to the Holm-Hansen method than to the Welschmeyer method, only data derived from Chl_a and Chl-a_Holm_Hansen_sF methods were retained. No corrections were applied to correct for differences in methodology.

Table A1.2. Methods associated with chlorophyll-a records in BioChem.

Method	Description
Chl_a	Unknown method
Chl_a_Holm-Hansen_F	Holm-Hansen method; Prefiltered; Frozen before analysis (-20)
Chl_a_Holm-Hansen_sF	Holm-Hansen method; Super Frozen before analysis (-196)
Chl_a_Welschmeyer_sF	Welschmeyer method; Super Frozen before analysis (-196)

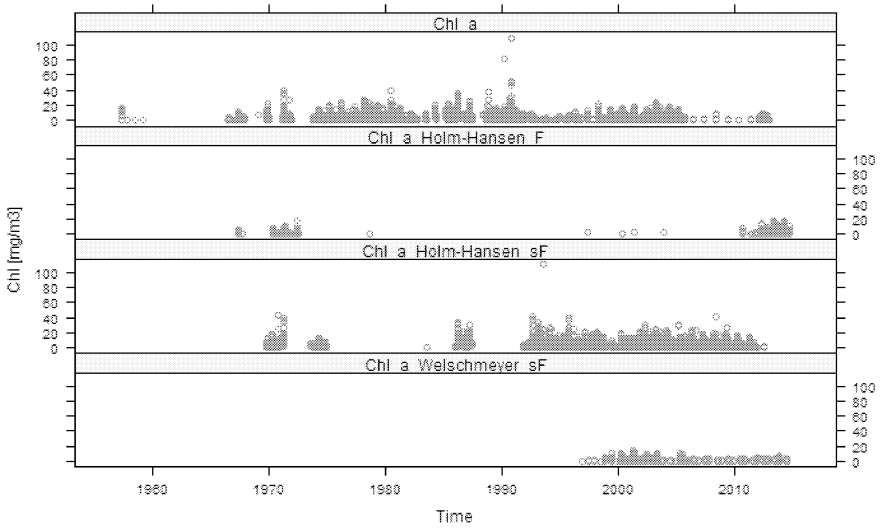

Figure A1.2. Time series of chlorophyll-a data from BioChem grouped by methods.

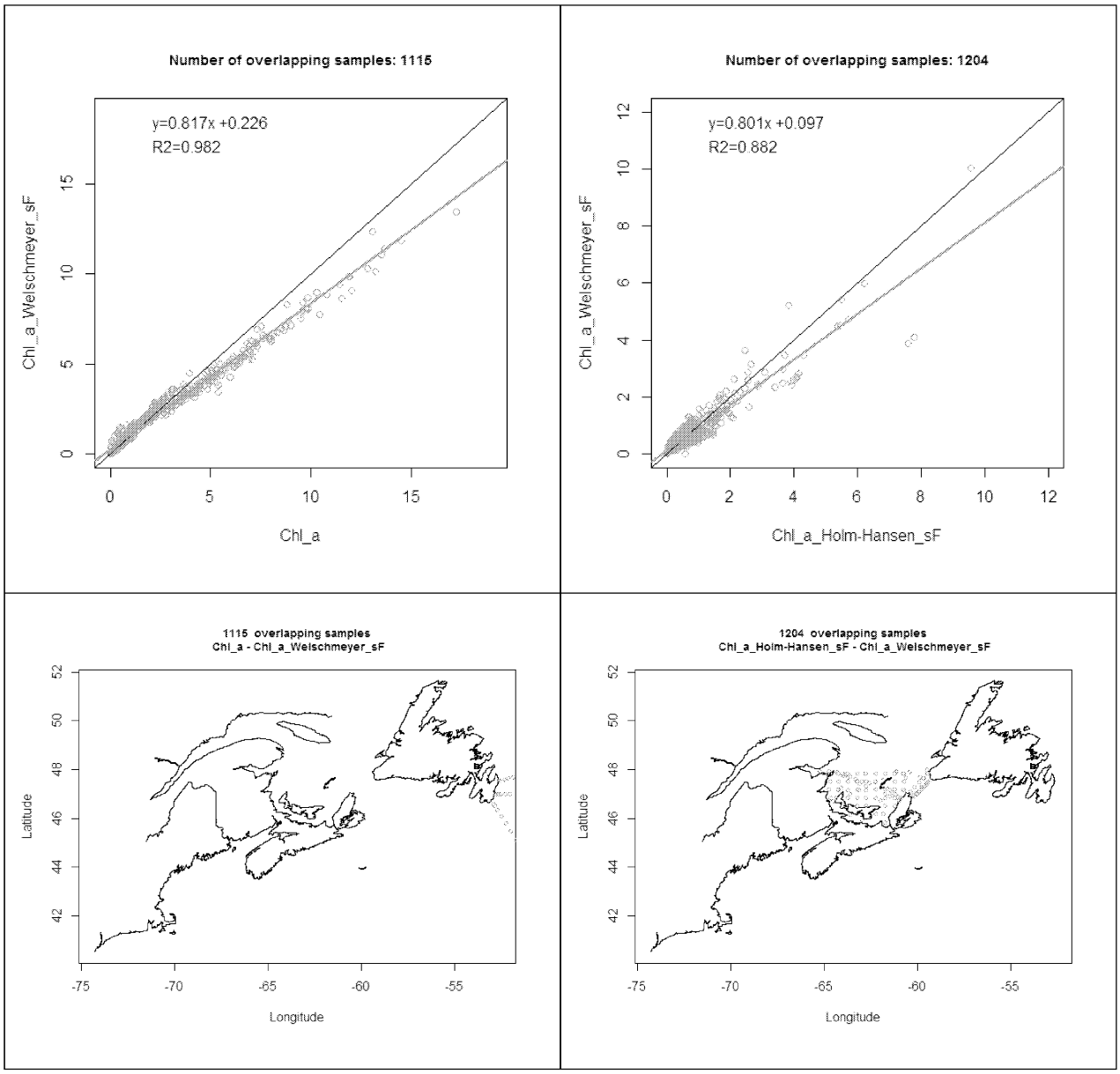

Figure A1.3: Comparison of the chlorophyll-a values collected using different methods is shown on the scatter plots on the top panel and the geographical locations of those samples is shown on the maps in the bottom panel.

NITRATE

Nitrate estimates are derived from 10 methods. The methods are listed and described in Table A1.3 and the time series of data associated with each method is shown in Figure A1.4. Most of the methods measure nitrate and nitrite together. We also included data for nitrate only since in most seawater the concentration of nitrite is small compared to that of nitrate.

Table A1.3. Methods associated with nitrate records in BioChem.

Method	Description
NO2NO3_0	Nitrate+Nitrite / Unknown method
NO2NO3_Alp_F	Nitrate+Nitrite / Alpchem / Frozen
NO2NO3_Alp_SF	Nitrate+Nitrite / Alpchem / SuperFrozen
NO2NO3_S&P1968	Nitrate+Nitrite/ S&P(1968) / filtered and frozen
NO2NO3_Tech_F	Nitrate+Nitrite / Technicon / Frozen
NO2NO3_Tech_Fsh	Nitrate + Nitrite / Technicon / Fresh / Strain / Unfiltered
NO2NO3_Tech_SF	Nitrate+Nitrite / Technicon / SuperFrozen
NO2NO3_Tech2_F	Nitrate+Nitrite / Technicon2 / Frozen
NO3_Tech_F	Nitrate / Technicon / Frozen, corrected for NO2
NO3_Tech_SF	Nitrate / Technicon / SuperFrozen

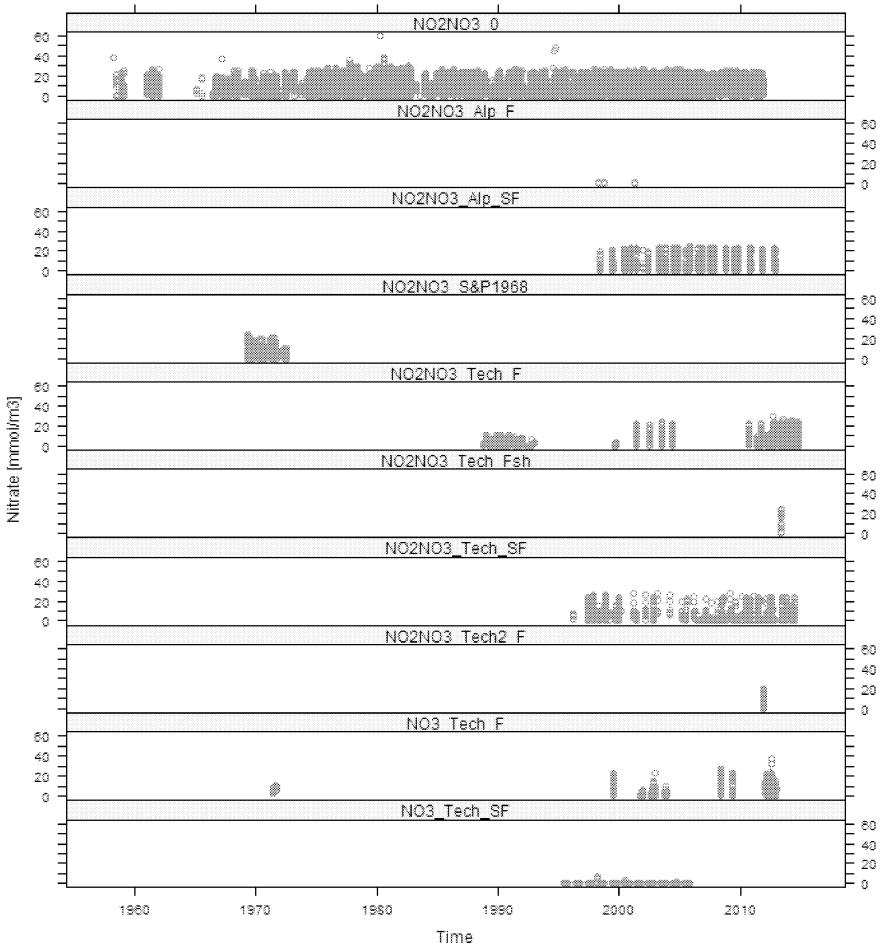

Figure A1.4: Time series of nitrate data from BioChem grouped by methods.

PHOSPHATE

Phosphate data available in BioChem are mapped to 7 methods. The methods are listed and described in Table A1.4 and the time series of data associated with each method is shown in Figure A1.5.

Table A1.4. Methods associated with phosphate records in BioChem.

Method	Description
PO4_0	Phosphate / Unknown method
PO4_Alp_SF	Phosphate / Alpchem / SuperFrozen / Filtered
PO4_Tech_2	Phosphate / Murphy and Riley / filtered and frozen
PO4_Tech_F	Phosphate / Technicon / Frozen / Unfiltered
PO4_Tech_Fsh	Phosphate / Technicon / Fresh / Strain / Unfiltered
PO4_Tech_SF	Phosphate / Technicon / SuperFrozen / Filtered
PO4_Tech2_F	Phosphate / Technicon2 / Frozen / Unfiltered

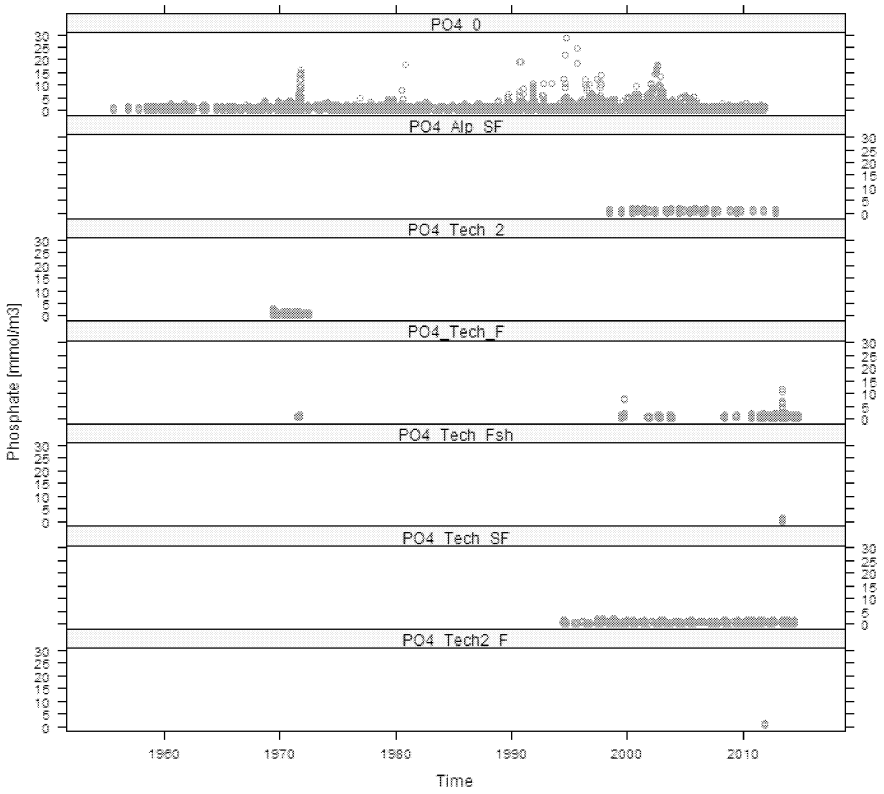

Figure A1.5: Time series of phosphate data from BioChem grouped by methods.

SILICATE

Silicate data available in BioChem are mapped to 8 methods (Table A1.5). Their time series of are shown on Figure A1.6.

Table A1.5. Methods associated with silicate records in BioChem.

Method	Description
SiO4_0	Silicate, Unknown methods and handling
SiO4_1	Silicate / Mullin and Riley / filtered and frozen
SiO4_Alp_F	Silicate / Alpchem / Frozen / Unfiltered
SiO4_Alp_SF	Silicate / Alpchem / SuperFrozen / Filtered
SiO4_Tech_F	Silicate / Technicon / Frozen / Strain / Unfiltered
SiO4_Tech_Fsh	Silicate / Technicon /Fresh /Strain / Unfiltered
SiO4_Tech_SF	Silicate / Technicon / SuperFrozen / Filtered
SiO4_Tech2_F	Silicate / Technicon2 / Frozen

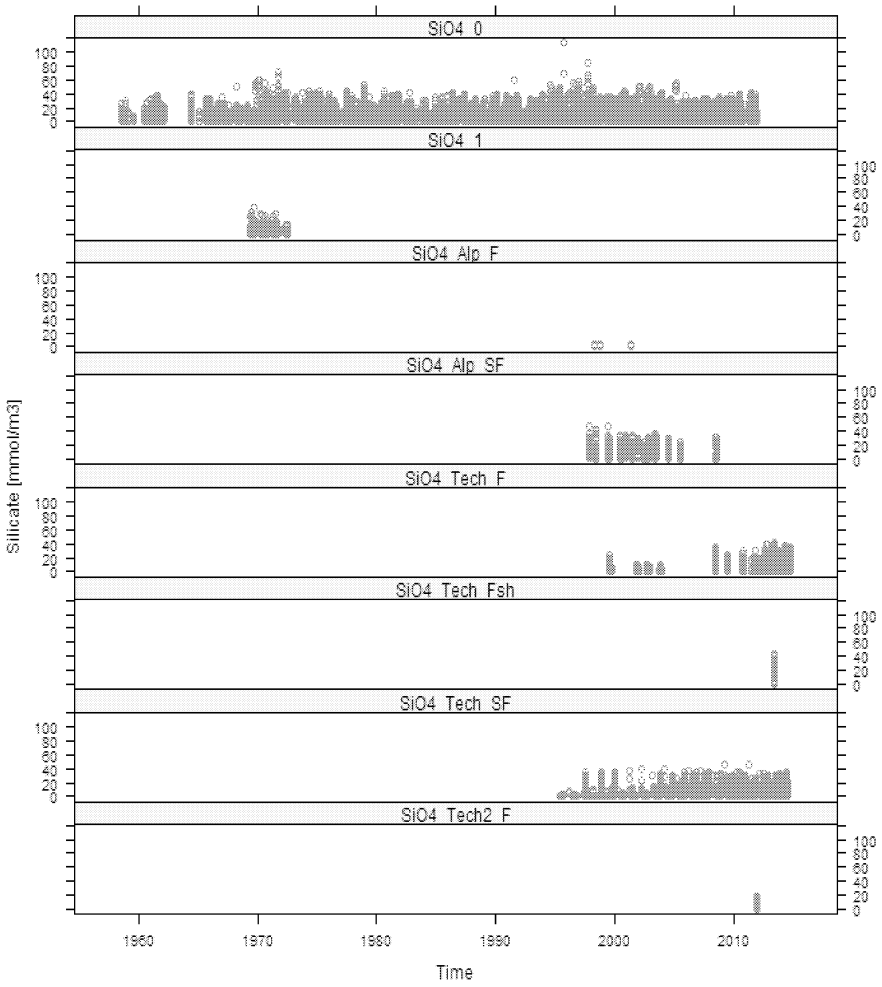

Figure A1.6. Time series of silicate data from BioChem grouped by methods.

ZOOPLANKTON

Zooplankton data was extracted from DFO's BioChem database (Devine et al. 2014) from 1914 to 2014. They were comprised of 687 missions and 53,787 samples, using 13 different kinds of nets, 35 different mesh sizes ranging from 20 microns to 4.23 mm, and various net deployment and sample processing protocols. To ensure data consistency and comparability, only samples collected and analyzed using Atlantic Zone Monitoring Program (AZMP) protocol (Mitchell et al. 2002) were retained for study, reducing the time scope to 1999-2014.

As AZMP samples are not always properly flagged in the BioChem database, a list of missions that followed the AZMP protocol were provided by Ocean and Ecosystem Science Division (OESD) and Ocean Data and Information Services (ODIS). The relevant missions include AZMP spring and fall cruises, summer and winter groundfish survey missions, bi-weekly sampling at fixed stations (Halifax Station 2 and Prince 5) and samples collected on the Scotian Shelf during Labrador Sea missions.

AZMP protocol samples zooplankton with Ring nets (0.75 m diameter, mesh size of 202 um) deployed as vertical tows from either near bottom or 1000 m (whichever is shallower) to the surface. The sample analysis includes estimation of abundance, species composition and

biomass in terms of wet and dry weight in two size fractions; one for organisms ranging from 0.2 mm to 10 mm in size and the other for all organisms larger than 10 mm. The protocol is as follows:

- Organisms larger than 10 mm are manually separated from the sample, identified and counted. Wet weight is determined and reported for each individual species. In addition total wet weight for all large organisms is reported as the sum of all individual wet weights.
- Captured organisms smaller than 10 mm (0.2 - 10 mm fraction) are identified and counted. Dry and wet weight is determined and reported for the whole sample containing all organisms in that size fraction.
- Total wet weight is reported for all captured organisms as the sum of wet weights of large and small organisms.
- Developmental stages are identified for *Calanus finmarchicus*, *C. glacialis* and *C. hyperboreus*.

Since the data hosted in BioChem is generally not subject to quality control and can contain erroneous records, substantial quality control was conducted to ensure correct representation of actual measurements. The quality control included verification of the following fields:

- time stamps: comparing mission dates with header dates and event dates start and end depths of the nets that cannot be equal or close together;
- volume of the samples: all records with volumes 0, or NA were removed;
- split fraction of the sample: all the records with split fraction NA, 0 or > 1 were removed;
- minimum and maximum sieve for dry weight records: records NA sieve were removed; and
- repeated records.

Finally, the numerical and biomass density for each species per unit surface area of a tow was computed as follows:

$$\text{abundance} = \text{counts} \times \frac{abs(\text{depth}_{\text{start}} - \text{depth}_{\text{end}})}{\text{split fraction} \times \text{volume}} \quad [\text{individuals}/\text{m}^2]$$

$$\text{biomass} = \text{weight} \times \frac{abs(\text{depth}_{\text{start}} - \text{depth}_{\text{end}})}{\text{split fraction} \times \text{volume}} \quad [\text{g}/\text{m}^2],$$

where counts refer to number of organisms encountered in the sample, $\text{depth}_{\text{start}}$ and $\text{depth}_{\text{end}}$ to the start and end depth of the net deployment, split fraction to the fraction of the sample analyzed and volume to the sample volume. The final filtered dataset includes 126 missions in the time period 1999 to 2014, with 2,367 net deployments and more than 400 taxonomic species.

APPENDIX 2. MATÉRN FUNCTION

The Matérn *correlation* function (Figure 33) is parameterised in a number of ways, and nomenclature of variables have also been inconsistent and can potentially cause confusion. The geoR library (Diggle and Ribeiro 2007; Ribeiro and Diggle 2001) defines it as:

$$\rho(x) = \frac{1}{2^{\kappa-1}\Gamma(\kappa)}\left(\frac{x}{\phi}\right)^{\kappa} K_{\kappa}\left(\frac{x}{\phi}\right),$$

where, $\phi > 0$ is the "range parameter"; $\kappa > 0$ is the shape (smoothness) parameter; $K_{\kappa}(\cdot)$ is the modified Bessel function of the third kind of order κ; and $\Gamma(\cdot)$ is the Gamma function. It is also related to the fractal dimension of the surface complexity (Constantine and Hall 1994).

spBayes's (Finley et al. 2007) parameterization just a little different as well as is the nomenclature:

$$\rho(x) = \frac{1}{2^{\nu-1}\ \Gamma(\nu)}(\phi x)^{\nu} K_{\nu}(\phi x).$$

INLA's (Lindgren and Rue 2015) parameterization is the same as spBayes', but nomenclature is slightly different:

$$\rho(x) = \frac{1}{2^{\lambda-1}\ \Gamma(\lambda)}(\kappa x)^{\lambda} K_{\lambda}(\kappa x).$$

Thus, the following identities are important to interpret the discussions and outputs from these authors:

$$\begin{aligned} \kappa_{geoR} &\equiv \nu_{spBayes} \equiv \lambda_{INLA} \\ 1/\phi_{geoR} &\equiv \phi_{spBayes} \equiv \kappa_{INLA}. \end{aligned}$$

Additionally, INLA defines $range_{13\%} = \sqrt{8\lambda}/\kappa$ (see rationale below).

The Matérn *covariance* function, $\gamma(x)$ is the correlation function $\rho(x)$ scaled by the variance. An offset of τ^2 the variability at local scales associated with sampling error smaller than the unit of measurement (sometimes called "nugget" variance) is also modeled:

$$\gamma(x) = \tau^2 + \sigma^2(1 - \rho(x)).$$

When $\nu_{spBayes} = 1/2$, this become the exponential model. When $\nu_{spBayes} \to \infty$, the model becomes the Gaussian model. The curves become only incrementally different once $\nu_{spBayes} > 2$ and so Finley et al. (2007) suggests limiting the prior to the interval (0,2) as a pragmatic solution to speeding up MCMC convergence. We have used the interval $\nu_{spBayes} = (0{,}5)$, just to be sure. Further, the effective range of spatial dependence (distance at which the correlation drops to 0.05 is given by $-ln(0.05)/\phi_{spBayes}$ (Finley, Banerjee, and Carlin 2007). As such, they recommend a uniform prior in the interval of $(\phi_{spBayes}, -ln(0.05))$.

The spatial scale we define as exactly this practical or effective spatial range: the distance at which spatial dependence drops asymptotically to $\rho(x) \to 0.05$.

One of the reasons for the popularity of the Matérn covariance is that it is a stationary solution to the SPDE:

$$(\kappa^2 - \Delta)^{\alpha/2}(\tau\xi(s)) = W(s),$$

where $W(s)$ is Gaussian spatial white noise and τ controls the variance and κ is the scale parameter. INLA defines the effective range at $\sqrt{8}/\phi_{spBayes}$, the approximate distance where correlation falls to 0.13 (vs 0.05):

$$\begin{cases} \lambda & = \alpha - d/2 \\ \sigma^2 & = \dfrac{\Gamma(\lambda)}{\Gamma(\alpha)(4\pi)^{d/2}\kappa^{2\lambda}\tau^2} \end{cases},$$

which for d=2 dimensions:

$$\begin{cases} \lambda & = \alpha - 1 \\ \sigma^2 & = \dfrac{\Gamma(\lambda)}{\Gamma(\alpha)(4\pi)\kappa^{2\lambda}\tau^2} \end{cases},$$

and $\alpha = 2$ by default and so $\lambda = 1$ such that:

$$\begin{cases} range & = \sqrt{8}/\kappa \\ \sigma^2 & = \dfrac{1}{4\pi\kappa^2\tau^2} \end{cases},$$

$$\text{range} = \sqrt{8}/\kappa.$$

APPENDIX 3. ADVECTION-DIFFUSION STOCHASTIC PARTIAL DIFFERENTIAL EQUATION (SPDE)

Following the development of Sigrist et al. (2015), we begin with the general regression model

$$Y(\mathbf{s},t) = \mu(\mathbf{s},t) + e(\mathbf{s},t),$$

where, $\mu(\mathbf{s},t) = x(\mathbf{s},t)^T\beta(\mathbf{s},t)$ is the mean process and $e(\mathbf{s},t)$ the residual error. This error process can be separated into a spatiotemporally structured component ω and an unstructured component ε: $e(\mathbf{s},t) = \omega(\mathbf{s},t) + \varepsilon(\mathbf{s},t)$. The *unstructured* error is usually assumed to be a white error process: $\varepsilon(\mathbf{s},t) \sim N(0,\sigma_\varepsilon^2)$.

The structured error $\omega(\mathbf{s},t)$ can be defined in terms of the following advection-diffusion SPDE:

$$\frac{\partial}{\partial t}\omega(\mathbf{s},t) = -\mathbf{u}^T\nabla\omega(\mathbf{s},t) + \nabla\cdot\Sigma\nabla\omega(\mathbf{s},t) - \zeta\omega(\mathbf{s},t) + \epsilon(\mathbf{s},t),$$

where, $\mathbf{s} = (x,y)^T \in \Re^2$: $\mathbf{u} = (u_x,u_y)^T$ parameterizes the drift velocity (advection); $\nabla = (\frac{\partial}{\partial x},\frac{\partial}{\partial y})^T$ is the gradient operator; $\nabla\cdot\mathbf{F} = (\frac{\partial F_x}{\partial x},\frac{\partial F_y}{\partial y})^T$ is the divergence operator for a vector field $\mathbf{F} = (F_x,F_y)^T$; $\Sigma^{-1} = \frac{1}{\phi_d^2}\begin{pmatrix}\cos\alpha & \sin\alpha\\ -\gamma\cdot\sin\alpha & \gamma\cdot\cos\alpha\end{pmatrix}^T\begin{pmatrix}\cos\alpha & \sin\alpha\\ -\gamma\cdot\sin\alpha & \gamma\cdot\cos\alpha\end{pmatrix}$ parameterizes the anisotropy in diffusion via ($\gamma > 0$, $\alpha \in [0,\pi/2]$) with $\phi_d > 0$ parameterizing the diffusion range; $\zeta > 0$ parameterizing local damping; and $\epsilon(\mathbf{s},t)$ parameterizing a Gaussian random field that accounts for source-sink processes with white noise in time and Matérn spatial covariance (aka, "innovation").

If $\epsilon(\mathbf{s},t)$ is stationary and has the form of a Whittle spatial covariance function, then it has the following spectrum:

$$\widetilde{f}(\mathbf{k}) = \frac{\sigma^2}{(2\pi)^2}(\mathbf{k}^T\mathbf{k} + \frac{1}{\phi_s^2})^{-(\nu+1)},$$

where $\mathbf{k}$ are the spatial wave numbers. The spectrum of the $\omega(\mathbf{s},t)$ process is then:

$$f(w,\mathbf{k}) = \widetilde{f}(\mathbf{k})\frac{1}{(2\pi)}((\mathbf{k}^T\Sigma\mathbf{k}+\zeta)^2 + (w+\mathbf{u}^T\mathbf{k})^2)^{-1},$$

where w is temporal frequency. The covariance function can be recovered as:

$$\begin{aligned} C(\mathbf{s},t) &= \int f(w,k)\ exp(i\cdot tw)\ exp(i\cdot\mathbf{s}'\mathbf{k})\ d\mathbf{k}dw \\ &= \int \widetilde{f}(\mathbf{k})\frac{exp(-i\cdot\mathbf{u}^T\mathbf{k}t - (\mathbf{k}^T\Sigma\mathbf{k}+\zeta)|t|)}{2(\mathbf{k}^T\Sigma\mathbf{k}+\zeta)}\ exp(i\cdot\mathbf{s}'\mathbf{k})\ d\mathbf{k}. \end{aligned}$$

Upon discretization:

$$\begin{aligned} \omega(\mathbf{s},t) &= \boldsymbol{\phi}(\mathbf{s})^T\alpha(t) \\ &\approx \sum_{j=1}^{K}\phi_j(\mathbf{s})\alpha_j(t) \\ &\approx \sum_{j=1}^{4}\phi_j^{(cos)}(\mathbf{s}_l)\alpha_j^{(cos)}(t) + \sum_{j=5}^{K/2+2}(\phi_j^{(cos)}(\mathbf{s}_l)\alpha_j^{(cos)}(t) + \phi_j^{(sin)}(\mathbf{s}_l)\alpha_j^{(sin)}(t)), \end{aligned}$$

where $\mathbf{k} = (k_{x,j}, k_{y,j})^T$ is the spatial wavenumber of the j component of K Fourier components and $\phi_j(\mathbf{s}) = \exp(\iota \cdot \mathbf{k}_j^T \mathbf{s}) = \{\cos(\mathbf{k}_j^T \mathbf{s}), \sin(\mathbf{k}_j^T \mathbf{s})\}$ is the spatial function. And, for each time t and location s_l, $l = 1, \ldots, n^2$ in the SPDE:

$$\begin{aligned} \mathbf{u}^T \nabla \phi_j^{(cos)}(\mathbf{s}_l) &= -\mathbf{u}^T \mathbf{k}_j \phi_j^{(sin)}(\mathbf{s}_l) \\ \mathbf{u}^T \nabla \phi_j^{(sin)}(\mathbf{s}_l) &= -\mathbf{u}^T \mathbf{k}_j \phi_j^{(cos)}(\mathbf{s}_l), \end{aligned}$$

and,

$$\begin{aligned} \nabla \cdot \Sigma \nabla \phi_j^{(cos)}(\mathbf{s}_l) &= -\mathbf{k}_j^T \Sigma \mathbf{k} \phi_j^{(cos)}(\mathbf{s}_l) \\ \nabla \cdot \Sigma \nabla \phi_j^{(sin)}(\mathbf{s}_l) &= -\mathbf{k}_j^T \Sigma \mathbf{k} \phi_j^{(sin)}(\mathbf{s}_l). \end{aligned}$$

The full non-separable, advection-diffusion model specification is thus:

$$\begin{aligned} Y(\mathbf{s},t) &= x(\mathbf{s},t)^T \boldsymbol{\beta} + \omega(\mathbf{s},t) + \varepsilon(\mathbf{s},t) \\ \omega(\mathbf{s},t) &= \boldsymbol{\Phi}\boldsymbol{\alpha}(\mathbf{s},t) \quad \{\text{advection} - \text{diffusion model}\} \\ \alpha(\mathbf{s},t) &= \mathbf{G}\boldsymbol{\alpha}(\mathbf{s},t-1) + \hat{\epsilon}\,(\mathbf{s},t) \quad \{\text{transition model}\} \\ \varepsilon(\mathbf{s},t) &\sim N(\mathbf{0}, \tau^2 \mathbf{1}) \quad \{\text{unstructured error}\} \\ \hat{\epsilon}\,(\mathbf{s},t) &\sim N(\mathbf{0}, \widehat{\mathbf{Q}}) \quad \{\text{innovation}\}, \end{aligned}$$

where, $\boldsymbol{\alpha}(\mathbf{s},t)$ are Fourier coefficients; $\boldsymbol{\Phi} = [\boldsymbol{\phi}(\mathbf{s}_1), \ldots, \boldsymbol{\phi}(\mathbf{s}_N)]^T$ is a matrix of spatial basis functions; $\mathbf{G}$ is the transition (propagator) matrix; and $\widehat{\mathbf{Q}}$ is the innovation covariance matrix (residual errors). The Fourier functions are:

$$\boldsymbol{\phi}(\mathbf{s}_l) = \left(\cos(\mathbf{k}_1^T \mathbf{s}_l), \ldots, \cos(\mathbf{k}_4^T \mathbf{s}_l), \cos\left(\mathbf{k}_5^T \mathbf{s}_l\right), \sin\left(\mathbf{k}_5^T \mathbf{s}_l\right) \ldots, \cos\left(\mathbf{k}_{\frac{K}{2}+2}^T \mathbf{s}_l\right), \sin\left(\mathbf{k}_{\frac{K}{2}+2}^T \mathbf{s}_l\right)\right)$$

APPENDIX 4. LOGISTIC MODEL

The derivation of the logistic model presented below is more phenomenological than mechanistic and attributed to Lotka (1925). It is our opinion that this phenomenological interpretation renders it useful as a general characterisation of system state. The argument is that the rate of change in time t of any state Y (in our context: abundance, species richness, "habitat", size) can be expected to be in some way, a function of itself:

$$dY/dt = g(Y).$$

It is expected that when $Y = 0$, dY/dt will also be zero and so represents an algebraic root of g. A Taylor series expansion of g near this root $Y = 0$ gives:

$$\begin{aligned} dY/dt &= g'(0)Y + g''(0)Y^2/2 + \text{higher order terms} \ldots; \\ &\approx Y[g'(0) + g''(0)Y/2]. \end{aligned}$$

With the identities $g'(0) = r$ and $g''(0) = -2r/K$, the standard form of the logistic equation is obtained:

$$dY/dt \approx rY(1 - Y/K).$$

The intrinsic rate of increase, r, is, therefore, some abstract and aggregate function that describes the net increase or decrease of the system state Y when Y is small. In biological systems, this means a maximum rate of growth, recruitment, mortality, movement, climatic change, extinction, speciation, etc. as the rate is expected to decline as it approaches some upper limit K of the magnitude of the system state Y.

With normalization by K such that $y = Y/K$:

$$dy/dt \approx ry(1 - y).$$

Many variations of this basic model are known, mostly different ways of adjusting the shape of the curve and/or the location of the inflection point (i.e., $K/2$). A flexible family is the gamma-logistic:

$$dy/dt = ry^{\alpha}(1 - y)^{\beta} + f(\ldots).$$

The additional parameters exponentiate different components which ultimately amounts to adding higher order and even fractional order terms in the Taylor series) and also adding additional terms $f(\ldots)$ that are external to the dynamic that r and K govern, such as fishing, advection, diffusion, noise. For the purposes of this discussion, we will use only the basic model and estimate the parameters of interest, $\theta = \{r, K\}$, but other parameterizations are possible, such as $\theta = \{r, K, \alpha, \beta\}$. The intent is to explore the utility of this more flexible formulation in conjunction with the basic model.

In discrete form, where $\Delta t = 1$ year and after a Euler discretization, the basic model becomes:

$$y_t \approx r y_{t-1}(1 - y_{t-1}).$$

This, we call the "basic" form of the discrete logistic model.